THE COST OF PASSIVE SOLAR ENERGY

by

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ABSTRACT

THE COST OF PASSIVE SOLAR ENERGY BY JOHN I. MEYER

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE MAY 1977 IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE IN ADVANCED STUDIES.

This report evaluates the total cost of passive solar design.

Faced with a barrage of issues dealing with passive solar energy, I found it difficult to design responsible buildings without a comprehensive understanding of the amount of money involved, and the value of my architectural preferences.

This report is my attempt to discover the important passive issues, quantify their impact on building costs, and weigh their compatibility with my aesthetic objectives. The goal of this report is a complete set of design guidelines which include both mechanical and aesthetic objectives.

The Introduction explains the measurement techniques for computing mechanical costs. Chapter I is a reprint of my original framework written six months ago at the beginning of this report. Chapters II-V are the core of this thesis. They analyse separately each of my four categories of passive issues: landscape, shape and orientation, windows, and materials. Chapter VI collects and orders the objectives of the four preceding chapters. Chapter VII demonstrates the use of the combined objectives in the design of a test case.

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PROBLEM DEFINITION

The purpose of this thesis is to develop guidelines to be used by a design-oriented architect. They are to be used in the creation of beautiful and economical buildings which operate in close harmony with passive solar energy systems.

Passive solar design is here defined as the manipulation of ordinary building parts to maximize the advantages, or minimize the disadvantages, of a given sun climate.

The word "solar" in this thesis title will often seem unjustified, as when night-time thermal barriers are analyzed, but all of the following discussions may be retraced to the desire to optimize the use of the sun's heat and light.

Active systems, like the flat plate collector, are not discussed in this thesis because it is necessary to develop an understandable framework for the ordinary systems of a building before collectors are nailed to the roof. It is the efficiency of the building below that dictates the number of collectors above.

The reader of this report need not worry about missing the "technological boat." Passive and active systems are differentiated more by equipment than by approach. The equation for the absorption of sunlight by a brick is the same used to determine the absorption of special collector paints.

AUTHOR'S RECENT DISILLUSIONMENT

Throughout the course of my architectural education, I have carried with me the notion that someone out there knew these things; that a quantified understanding of the full range of passive energy issues was just another part of ordinary practice. Mechanical engineers, I supposed, helped architects program sensible buildings.

Now after working with large architectural/engineering offices, I have changed my mind. If I might briefly mention some work experiences of the past two years, the reasons for my disillusionment may become apparent.

*Last year I helped design

a transit system for downtown St. Paul which had to thread its way among glass towers S.O.M. had proposed for the coldest large city on earth.

*I was given charge of the design of a prefabricated housing system for Nigeria. In this case I was answerable to a promoter whose only concern was that soil pipes align. No coordination of building mechanical systems and local climate ~~were~~ was desired.

*I have worked on designs for three "solar" buildings, all of which were purported to be developed with the active participation of mechanical engineers. The most successful of the three has received professional awards from the most fashionable group of American architects and has recently been published by New York's Museum of Modern Art. When visiting the site with that project's chief designer this winter, I was shocked to find frost on the inside of an exterior wall, and to hear him explain that insulation would have destroyed the integrity of his concrete wall.

These three recent experiences have helped convince me that if guidelines for reasonable passive design exist they are not commonly used and that there is a pressing need for a comprehensive overview of the costs of passive solar enengy.

COMPREHENSIVE SCOPE

There have been many times during the production of this thesis when I have been browbeaten by well-meaning readers. They have correctly pointed out that the scope of this work is too large for one person with merely an architectural background. They have pointed out that any of the sub-chapters would be suitable for a more precise and managable report.

I have only one defense against these most reasonable arguments: whether he choses to ignore the fact or not, whenever an architect picks up a pencil to design a building he assumes responsibility for <u>all</u> passive energy concerns. The shape he gives his building, the landscaping of that building, its openings and materials, all have an important impact on the energy consumption and mechanical equipment required.

An architect cannot beg off by simply stating that he is not a mechanical engineer because only architects design buildings. The mechanical engineer's current role is to make architect-designed buildings habitable.

An architectural education does not presently equip students with an understanding of the costs and savings of passive energy decisions. Therefore, it is necessary for each student to equip himself. The first step, which this thesis attempts to take, is to collect the full range of passive solar issues and test them for an understanding of their impact on overall building costs.

ERRORS

Because of the scope of this work, errors will undoubtedly occur. The reader who is interested only in precision documents written by eminently qualified professionals may stop now. For those who are less demanding, I would make a suggestion concerning the most useful way to read this report.

Two types of numerical information are presented. One type is the very reliable charts and data extracted from engineering catalogues. This reliable information will always be reproduced in hardline graphs. The second type of numerical information is that which has been processed by the author for his various purposes. The unofficial information will always be presented in free-hand graphs.

It is important for the reader who wants to use the conclusions of this report to understand the author's assumptions, and to trace all numerical information from official to unofficial graphs.

PROCEDURE OF INVESTIGATION

The investigating procedure of this thesis will follow the order of the 7 chapters.

*Chapter I will state the starting point of this investigation: my original vague notions that prompted this thesis. It will also include the building model to be used in the detailed investigations of the following chapters.

*Chapters II-V are the core of this report. Each of these chapters will be devoted to a category of passive energy issues: II Landscape, III Windows, IV Shape and Orientation, V Materials.

Each chapter will present the complete list of issues included in that category, known to the author. Chapter V, for example, is composed of 4 "material" issues: insulation, mass, color, and texture.

A numerical means of measuring the importance of each issue will be proposed. Costs of various manipulations are calculated and the issues of each chapter are ranked according to their impact on an overall building budget.

My aesthetic values that touch each issue will also be discussed and combined with the mechanical objectives.

*Chapter VI combines the objectives of all the chapters into one quantified set of guidelines. At this point, I can state with some degree of confidence whether window area is a more important concern than a building's orientation, or whether sunscreens are a better investment than an extra inch of insulation.

*Chapter VII is a test case to see if these nine months of work have produced reliable tools for the proper use of passive solar energy. In this final chapter, the redesign of a building presently under construction in the Boston area will be taken to a sufficient stage of completion where the architect, developer, and mechanical engineer of the real project can judge if any significant savings have been achieved and if so, at what cost to the quality of the envionment created.

MEASUREMENT TECHNIQUE

All results of the tests performed throughout this thesis should be easily understood by an American businessman. The savings produced by the proper use of passive energy principals, therefore, will be translated into per cent reductions from a building's total construction cost.

Today most blue chip commercial building projects are "set up" to pay for themselves in a period of five years. In other words, in order to comfortably cover financing costs, the income from a building must match its first cost and operating cost within five years of its completion. Therefore, five years of energy reductions must be added to the first cost reductions in mechanical equipment in order to determine the advantage of any energy conserving technique.

The price of energy is rising faster than inflation, but for the purpose of the measurements in this thesis, it is only assumed to keep pace with inflation.

The savings produced by each correct building technique will be graphically displayed throughout this report by the use of "price tags":

PRICE TAG.

"TITLE OF OPERATION PERFORMED"	% COST REDUCTION	
	APARTMENT	OFFICE
1^{ST} COST		
$5^{YR.}$ ENERGY		
TOTAL		

These "price tags" are intended to give a quick representation of the reduction of a building's total cost produced by a particular construction method or material.

In order to quantify the percent of savings to be listed on the "price tag," a listing of average mechanical and annual energy costs for the Boston area is necessary (Chart 1.1).

To enter the percent savings of some energy conserving technique, the per cent load reduction is multiplied by the proper percentage on Chart 1.1. For example, if a special type of sunscreen reduces apartment cooling loads by 10%, the "price tag" would be filled in as follows:

SPECIAL SUNSCREEN	% COST REDUCTION
	APARTMENT
1^{ST} COST	$10\% \times 3\% = .3\%$
5^{YR} ENERGY	$10\% \times 30\% \times (.80/35) \times 5 = .3\%$
TOTAL	$.6\%$

The energy savings is multiplied by \$.80/\$35 because that is the ratio of annual square foot energy costs related to square foot construction costs.

Thus all savings are reduced to the first cost figures easily comprehended by a businessman.

MODEL CASE

In order to avoid the problem of producing a cookbook of ideas with no clear understanding of their relative importance, all of the experiments in this thesis are related to one specific location (Boston). The model building type is a five story, 70 foot deep building. It costs $35 per square foot and is constructed as illustrated in Figure 1.2.

While the use of such a specific model limits its application to the Boston area, one case is clearly presented. Once the technique for calculating costs is understood,

CHART 1.1

FIRST COST	% OF CONSTRUCTION COST	
	APARTMENT	OFFICE
HEATING	5%	8%
AIR CONDITIONING	3%	8%
LIGHTING	1%	6%

* SOURCE: MEANS ** CORRECTED .75 FOR EQUIPMENT TO LOAD RATIO

ENERGY BILL	% OF ENERGY BILL	
	APARTMENT	OFFICE
HEATING	60%	20%
AIR CONDITIONING	30%	25%
LIGHTING	10%	50%

* CONSENSUS OF CONSULTING ENGINEERS

charts may be reconstructed to suit other climates and construction methods.

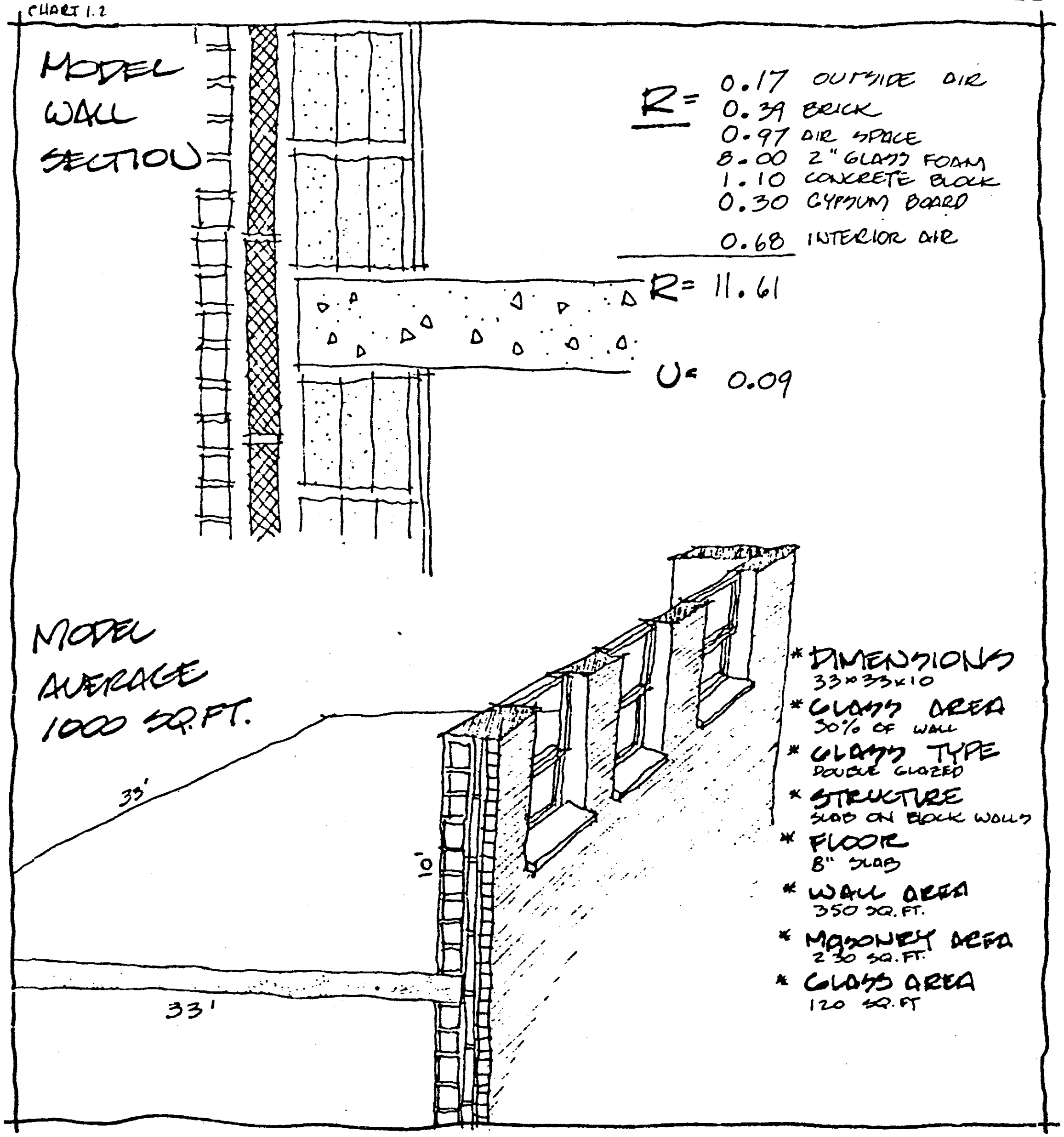
OFFICES AND APARTMENTS

Offices and apartments are both designated for testing because they are logical choices for the test case location, and because these two uses point out the differences between heavily populated interior climates and less populated housing situations.

TEST CASE

A test case is to be designed for the final chapter of this thesis. A visually sensitive site on the edge of Boston's

CHART 1.2



i

North End has been purposely chosen to demonstrate that energy conscious design need not overwhelm its surroundings.

I INITIAL FRAMEWORK

STARTING POINT

Pooling the information I've gathered during five years of doing architecture, I begin this report by patching together the pieces of my own knowledge concerning the role of passive energy in the world of architecture.

I found that I could group those pieces of information into four distinct categories:

1) Landscaping
2) Shape and Orientation
3) Windows
4) Materials

I have evaluated these four categories with a group of objectives that deal with either the economy of building operation or the human desirability of the spaces created.

DEVELOPMENT OF OBJECTIVES

Architecture is an ambivalent pursuit of economy and commodity.

That a blind pursuit of energy efficiency results in human "disasters" is a well documented fact. For this reason, it is impossible to write a set of energy objectives without taking human concerns into account.

After some soul searching, I have postulated the following two-part list of ordered objectives.

SOFT AND HARD

The straight optimization of energy efficiency will lead only to the design of well-insulated opaque cubes. Such ungoverned solutions are a waste of everyone's time.

The hard dollar and cents issues discussed in this report all have soft implications. The artistic use of natural lighting, for instance, is inextricably bound to the heat loss and gain of a building.

The framework I am now attempting to develop and illustrate will include both the hard and soft issues of passive solar design.

CHAPTER SUMMARY

Chapter I will be the statement of my initial framework. This beginning framework is the ordering of information acquired through personal experience. The middle chapters (Chapters II

-V) will be critical analysis of the individual pieces of my initial framework. Chapter VI will be the restructuring of the framework in light of new and quantified information. Finally, Chapter VII will be a test case pitting this new approach against the approach taken for the recent development of a Boston property.

HUMAN OBJECTIVES

1) Adequate and delightful natural lighting

4) Pleasing appearance

5) Adequate indoor-outdoor connections

7) Positive community impact

8) Pleasing views

9) Adequate range of lifestyle options

ENERGY OBJECTIVES

2) Minimize construction costs

3) Minimize operation costs

6) Maximize building utility and flexibility

FIRST FRAMEWORK

Using my own experience and my nine ordered objectives, I may now propose to order the importance of the four categories that include all the problems of passive solar energy.

This ordering,

1) shape and orientation
2) windows
3) landscaping
4) materials,

represents my first stab at ordering passive energy issues. This should readjust and expand several times during the course of my study. Especially noteworthy will be the adjusted, quantified frameworks appearing after the completion of my theoretical investigation (Chapter VI) and again after completion of the test problem (Chapter VII).

2 LANDSCAPE

LANDSCAPING

II LANDSCAPING

I was disappointed to find so little mechanical savings at stake by the manipulation of different parts of a building's landscape. I wanted to lead off with a category offering the opportunity for major mechanical savings.

In my mind, the way buildings fit into their site preceeds any discussion of the buildings themselves. It is, therefore, most natural to begin this analysis by discussing landscaping, despite its small effect on mechanical requirements.

Of the four categories of passive solar issues, 'landscaping' has the smallest impact on building costs. It is important that landscape issues be understood, however, because designers must realize where constraints do not exist as well as where they do.

COST ISSUES

Three landscape issues are considered important in this discussion:

1. Growing Things
   Trees, ivies, and various ground covers are those pieces of the plant world that affect a building's mechanical operation and installation costs.
2. Surrounding Objects
   'Surrounding Objects' are those objects near a building which reflect or intercept suffients amounts of heat and light to effect energy consumption.
3. Partially or Completely Buried Buildings
   Buried buildings would seem to offer economies because they are nestled in the constant moderate temperatures of sub-grade earth.

MODEL AND MEASUREMENTS

The 1000 square feet of space used throughout this report will serve as a model.

The method of evaluation is the comparative analysis of the 'wall charts' which have been constructed for display in the following pages. Some of these charts deal with average temperatures and may be used to compare energy consumption. Others present peak loads under worst conditions and are used to determine installation capacity.

All of the numbers in the wall charts are either well-known 'book values' or the products of simple calculations.

*Average Sun Gains are charted in dozens of publications.[1]

*Heat Loss is the product of a wall's conductance (book value) and the difference between the temperatures it divides.

*Infiltration is the amount of heat required to warm or cool replacement air which leaks through skin cracks or is me-

1. ASHRAE Handbook of Fundamentals is used in this report.

chanically exhausted. In the assumed model, 1/2 of the room's air must be replaced per hour in apartments. Office space will require a full air change.

*<u>Sun Waste</u> is the amount of extra sun heat which would overheat a winter room and would have to be exhausted. In this model the building's mass has more heat storage capacity than average daily sunheat. Therefore no sunheat is presumed to be wasted.

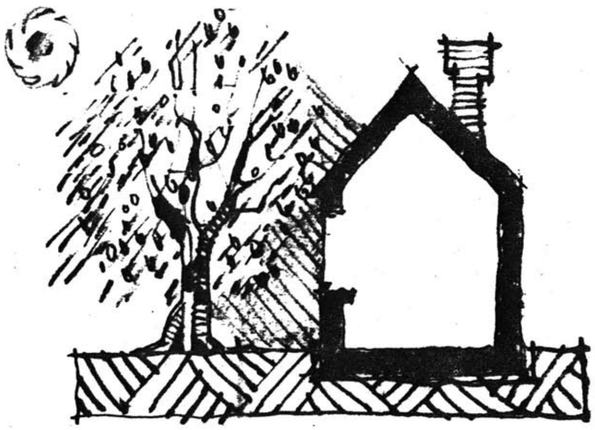
CHART 2.0 - ASHRAE SUN CHART

SOLAR HEAT GAIN FACTORS FOR 40°N LATITUDE, WHOLE DAY TOTALS
Btu/ft²/day (Values for 21st of each month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	118	162	224	306	406	**484***	422	322	232	166	122	98
NNE	123	200	300	400	550	**700***	550	400	300	200	123	100
NE	127	225	422	654	813	**894***	821	656	416	226	132	103
ENE	265	439	691	911	1043	**1108***	1041	903	666	431	260	205
E	508	715	961	1115	1173	**1200*†**	1163	1090	920	694	504	430
ESE	828	1011	1182	**1218*†**	**1191†**	1179	**1175†**	**1188†**	1131	971	815	748
SE	1174	1285	**1318***	1199	1068	1007	1047	1163	1266	1234	1151	1104
SSE	1490	**1509***	1376	1081	848	761	831	1049	1326	1454	1462	1430
S	**1630*†**	**1626†**	**1384†**	978	712	622	694	942	**1344†**	**1566†**	**1596†**	**1482†**
SSW	1490	**1509***	1370	1081	848	761	831	1049	1326	1454	1462	1430
SW	1174	1285	**1318***	1199	1068	1007	1047	1163	1266	1234	1151	1104
WSW	828	1011	1182	**1218*†**	**1191†**	1179	**1175†**	**1188†**	1131	971	815	748
W	508	715	961	1115	1173	**1200*†**	1163	1090	920	694	504	430
WNW	265	439	691	911	1043	**1108***	1041	903	666	431	260	205
NW	127	225	422	658	813	**894***	821	656	416	226	132	103
NNW	123	200	300	400	550	**700***	550	400	300	200	123	100
HOR	706	1092	1528	1924	2166	**2242***	2148	1890	1476	1070	706	564

*month of highest gain for given orientation(s)
†orientation(s) of highest gain in given month

SOURCE: ASHRAE, *Handbook of Fundamentals*, 1970; Koolshade Corporation.



PRICE TAG 2.1

ADVANTAGES OF PLACING 10 YR. OLD DECIDUOUS TREES IN FRONT OF WINDOWS	% COST REDUCTION					
	APARTMENTS			OFFICES		
	N	S	E/W	N	S	E/W
1ST COST	.5	.7	.9	.2	.3	.5
5 YR ENERGY	.4	.6	.8	.5	.7	1.0
TOTAL	.9	1.3	1.7	.7	1.1	1.5

PRICE TAG 2.1B

ADVANTAGE OF 10 YR. DECIDUOUS TREES	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.2	.3	.4	.1	.1	.2
5 YR ENERGY	.2	.2	.3	.2	.3	.4
TOTAL	.4	.5	.7	.3	.4	.6

Growing Things

Trees

When windows are shielded from sun rays by trees, air conditioning costs are reduced.

Most deciduous trees positioned between windows and the sun will reduce direct interior sunshine by 50%.[1] Chart 2.1 shows the load reductions for each apartment orientation made possible by the use of deciduous sunscreens. Chart 2.2 shows the load reductions for offices.

Energy and installation cost reductions are obtained by multiplying the load reductions by the percentage of a building's first cost listed in Chapter I. Cost reductions are listed in price tag 2.1

Most 10 year old trees operate at 85% of the efficiency of mature trees.[2] They are commonly installed and may be easily replaced. 10 year old trees have been legitimately used for calculating first costs as well as operating costs because they may be considered a permanent building part.

10 year old trees will shade only the lower 2 floors of the 5 story model building. Hence cost reductions for the model will be 2/5 of the reductions in the chart above. Price tag 2.1b shows the real savings possible by the use of deciduous trees.

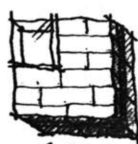
1. Olgyay, Victor, Design with Climate.

2. Ibid.

CHART 2.1 TREES AND APARTMENTS

1 SQ. FT.

BOSTON APARTMENT A.C. LOADS W/O TREES	SUMMER		
	N	S	E / W
AV. SUN GAINS BTU/H	2.6	4.4	7.1
SUN WASTE			
HEAT LOSS	2.4	2.4	2.4
INFILTRATION	2.7	2.7	2.7
TOTAL	7.7	9.5	12.2



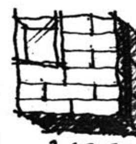
1 SQ. FT.

BOSTON APARTMENT A.C. LOADS WITH TREES BETWEEN SUN AND WINDOWS	SUMMER		
	N	S	E / W
AV. SUN GAINS BTU/H	1.3	2.2	3.6
SUN WASTE			
HEAT LOSS	2.4	2.4	2.4
INFILTRATION	2.7	2.7	2.7
TOTAL	6.4	7.3	8.6
% LOAD REDUCTION	17%	23%	30%

CHART 2.2 - TREES AND OFFICES

1 SQ. FT.

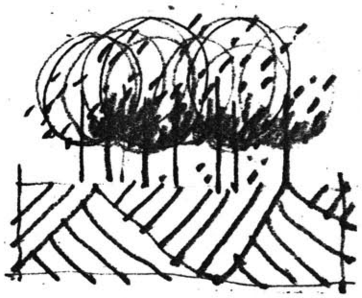
BOSTON OFFICE A.C. LOADS W/O TREES	SUMMER		
	N	S	E / W
AV. SUN GAINS BTU/H	2.6	4.4	7.1
SUN WASTE			
HEAT LOSS	2.4	2.4	2.4
INFILTRATION	5.4	5.4	5.4
OFFICE LOAD	12.4	12.4	12.4
TOTAL	21.8	24.6	27.3



1 SQ. FT.

BOSTON OFFICE A.C. LOADS WITH TREES BETWEEN SUN AND WINDOWS	SUMMER		
	N	S	E / W
AV. SUN GAINS BTU/H	1.3	2.2	3.6
SUN WASTE			
HEAT LOSS	2.4	2.4	2.4
INFILTRATION	5.4	5.4	5.4
OFFICE LOAD	12.4	12.4	12.4
TOTAL	20.5	22.4	23.7
% LOAD REDUCTION	7%	10%	15%

A Stand of Trees (Forest)



A stand of trees, a group of closely spaced mature trees, decreases ground temperatures 10°F on 90° days. The summertime climate of an entire neighborhood or district may be completely altered by the presence of trees. Price tag 2.2 lists the mechanical cost reductions produced by building beneath the canopy of a forest. Residential cooling costs are eliminated while office cooling must only accommodate the internal loads produced by people, lights, and machines.

PRICE TAG 2.2

BUILDING BENEATH A STAND OF TREES	% COST REDUCTION			
	APARTMENT	OFFICE		
		N	S	E/W
1ST COST	3	2.7	2.7	2.7
5YR ENERGY	3.4	1.2	1.2	1.2
TOTAL	6.4	3.9	3.9	3.9

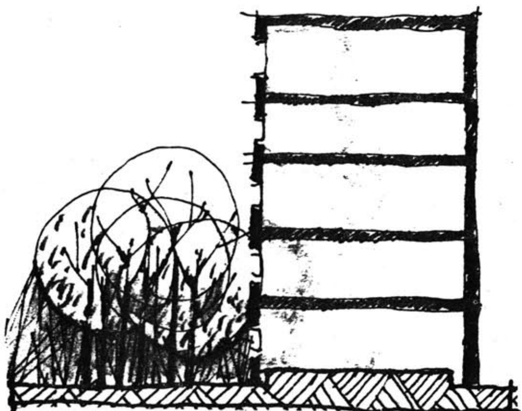
Actual reductions for the 5 story model would be 2/5 of the percentages listed because only 2/3 of a 5 story building will be beneath a tree stand.

Trees and Natural Lighting

Deciduous trees positioned between the sun and windows reduce natural lighting up to 50%. [No additional lighting fixtures are made necessary by this sunscreening effect because summer sunlight is twice as intense as in winter when trees are leafless.] Deciduous trees immediately outside windows keep lighting levels constant year round. Lighting bills will be slightly increased by halving available summer sunlight. Price tag 2.3 presents the lighting disadvantages of the use of deciduous sunscreens for a 70 foot deep building.

PRICE TAG 2.3

LIGHTING DISADVANTAGE OF USING DECIDUOUS SUNSCREENS FOR 70' DEEP BUILDING	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				0	0	0
5YR ENERGY				-.3	-.3	-.3
TOTAL				-.3	-.3	-.3



Again, these numbers apply only to the lower 2 floors of the model model structure.

The lighting penalty for the use of trees is small and only slightly affects building operation.

Tree Conclusion

The following price tag lists the cost advantages of planting 10 year old deciduous trees between summer sunshine and windows. (Lighting penalties are included.) The advantages of building beneath the canopy of a forest are not included because they result from a special condition.

PRICE TAG 2.5

TOTAL ADVANTAGE OF DECIDUOUS TREE SCREEN	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.5	.7	.9	.2	.3	.5
5YR ENERGY	.4	.6	.8	.2	.4	.7
TOTAL	.9	1.3	1.7	.4	.7	1.2

Ivy

If ivy is allowed to grow over windows during the cooling season its use will reduce costs in the same proportion as the use of deciduous trees.

If ivy is to be cleared from summer windows no mechanical reductions will result from its use.

Ground Covers and Reflected Heat

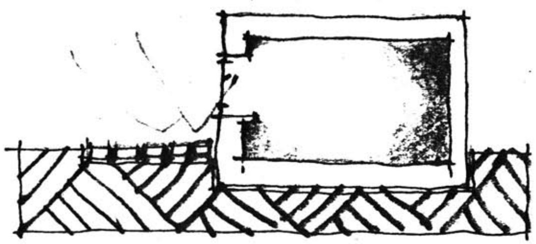
White paving reflects 80% of the sun's light and heat while grass reflects only 20%. White ground cover increases the amount of winter sunheat through a building's windows by 60%. Chart 2.4 compares a building with grass beneath its windows to a building with white paving positioned to reflect sunheat into its interior.

PRICE TAG 2.6

WINTER HEAT REFLECTION. WHITE PAVING VS. GRASS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	0	0	0	0	0	0
5YR ENERGY	.2	4.0	1.1	0	0	0
TOTAL	.2	4.0	1.1	0	0	0

Since all energy advantages of reflecting winter sunheat are offset by the disadvantages of summer reflected sunheat, a deciduous tree shade over the reflective ground cover is assumed in the above price tag.

Reflective ground covers do not effect office operation because additional reflected sunheat is insignificant beside internal office loads.



Ground Cover and Lighting

Reflecting light into windows has no appreciable effect on the energy bill of apartments for the following reason: Daytime lighting accounts for only 10% of a domestic lighting bill, and lighting accounts for only 10% of the total domestic energy bill. Reflected lighting, therefore,

CHART 2.4 - REFLECTIVE GROUND COVER

BOSTON AV. LOADS WITH GRASS REFLECTING SURFACE (1 SQ. FT.)	WINTER			SUMMER (UNSHADED)		
	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.8	11.0	3.6	2.6	4.4	7.1
SUN WASTE	0	0	0			
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2

BOSTON AV. LOADS WITH WHITE PAVING REFLECTING SURFACE (1 SQ. FT.)	WINTER			SUMMER (UNSHADED)		
	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	1.3	17.6	5.8	4.2	7.0	11.4
SUN WASTE	0	0	0			
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7
TOTAL	-16.5	-.2	-12.0	9.3	12.1	16.5
% LOAD REDUCTION	2.8%	60%*	15.5%	-20.8%	-27.4%	-35.2%

* 60% REPRESENT MAXIMUN SUNSHINE PROBABILITY

could at most reduce a domestic energy bill by .3%.

Office energy bills may be significantly reduced by the use of reflective ground cover. Daytime lighting accounts for 80% of an office lighting bill, and lighting represents 50% of an office's total energy bill. Since externally reflected light on a 30% glass wall supplies up to 20% of interior lighting, the use of reflective surfaces beneath windows produces a 10% reduction in office energy needs.

PRICE TAG 2.7

GROUND REFLECTED LIGHT [ASSUMING SUMMER SUNSHADES]	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST		0
5YR ENERGY		.7
TOTAL		.7

Surrounding Objects

Surrounding objects can steal light and sunshine from a building and considerably increase heating requirements. If, however, surrounding buildings are positioned to reflect sunlight onto a building, reductions in lighting and heating costs will result.

Mechanical loads before and after the construction of reflecting and obstructing buildings are compared in charts 2.5 and 2.6 The cost of these load changes are presented in the following price tags.

PRICE TAG 2.8

ADVANTAGE OF UNOBSTRUCTED VS. OVERSHADOWED BUILDING	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	0	0	0	0	0	0
5YR ENERGY	.2	4.1	1.2	.3	3.6	1.7
TOTAL	.2	4.1	1.2	.3	3.6	1.7

PRICE TAG 2.9

ADVANTAGE OF 80% REFLECTION ONTO A BUILDING	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	0	0	0	0	0	0
5YR ENERGY	-.1	3.9	.8	0	2.7	.7
TOTAL	-.1	3.9	.8	0	2.7	.7

The energy reductions in the first price tag above are correct when unobstructed buildings are equipped with sun shades. If windows are unshaded, no energy will be saved on the annual basis because summer cooling load increases will balance winter heat reductions.

These reductions are quite high, but they represent theoretical maximums and not ordinary conditions. All windows are assumed to receive 80% additional sunshine from reflection or to lose all direct sunshine by obstruction.

Normally a small proportion of a building's windows receive reflective sunshine. Only that small proportion of the listed reduction may be realized.

While it is more common for large portions of a building to be obstructed, it is usually difficult to move an urban structure completely out of the shadow of surrounding buildings.

CHART 2.5 — OVERSHADOWED APARTMENTS

 1 SQ. FT. BOSTON: APARTMENT AVERAGE CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0	X	X	X	X	X	X
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2

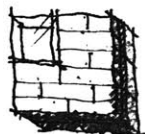
 1 SQ. FT. OVERSHADOWED APARTMENT	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.2	3.3	1.1	.8	1.3	2.1	.8	1.3	2.1
SUN WASTE	0	0	0	X	X	X	X	X	X
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.6	-14.5	-16.7	5.9	6.4	7.2	5.9	6.4	7.2
% LOAD REDUCTION	3.5%	60%	18%	-23%	-33%	-41%	0%	0%	0%

CHART 2.5B - OVERSHADOWED OFFICES

BOSTON OFFICE AV. LOADS

1 SQ. FT.

	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE LOADS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-14.9	-4.7	-12.1	22.8	24.6	27.3	21.0	21.5	22.3



" COMPLETELY OVERSHADOWED

1 SQ. FT.

	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	.8	1.3	2.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE LOADS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-15.5	-12.4	-14.6	21.0	21.5	22.3	21.0	21.5	22.3
% LOAD REDUCTION	-4%	-60%	-21%	8%	13%	18%	0%	0%	0%

CHART 2.6 — 80% REFLECTION ONTO AN APARTMENT

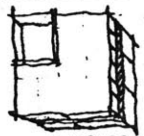
1 SQ. FT.

WITH REFLECTION	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	1.4	19.8	6.48	4.7	7.9	12.8	.8 (+.65)	1.3 (+1.0)	2.1 (+1.7)
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
	-16.4	2.0	-11.32	9.8	13.0	17.9	6.6	7.4	8.9

1 SQ. FT.

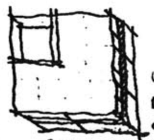
W/O REFLECTION									
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2
PERCENT LOAD DIF.	3.5%	100%	20.3%	-21%	27%	32%	10.6%	13.5%	19%

CHART 2.6B – 80% REFLECTION ONTO AN OFFICE



BOSTON OFFICE
AV. LOADS
1 SQ. FT.

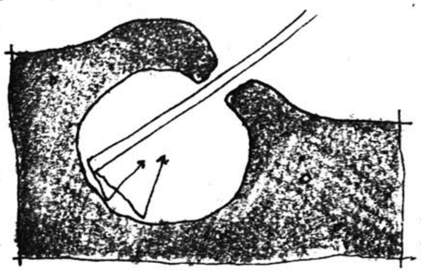
	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E / W	N	S	E / W	N	S	E / W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-14.1	-4.7	-12.1	22.8	24.6	27.3	21.0	21.5	22.3



"
WITH 80% REFLECTION ON ALL SURFACES
1 SQ. FT.

	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E / W	N	S	E / W	N	S	E / W
AV. SUN GAINS	1.4	19.8	6.48	4.7	7.9	12.8	.8	.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-13.5	4.1	-9.2	24.9	28.1	33	21.0	21.5	22.3
% LOAD REDUCTION	4%	60%	24%	9%	14%	21%	0%	0%	0%

Buried Buildings

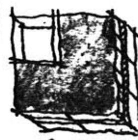


Four feet below the surface, earth holds a constant temperature of 55°F. The walls of a buried building separate a smaller temperature differential and therefore have smaller heat losses.

All the heating and cooling loads through a square foot of above grade wall have been compared to the mechanical loads of a square foot of sub-grade wall. The below grade space is credited with a skylight area of 30% of its wall area. The cost of the load

CHART. 2.7 — ABOVE GRADE VS. BELOW GRADE COMPARISON

APARTMENT BOSTON: AVE. CLIMATE INDUCED LOADS — 1 SQ. FT. — [ABOVE GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2



APARTMENT BOSTON: AVE. CLIMATE INDUCED LOADS — 1 SQ. FT. — [BELOW GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-6.7	-6.7	-6.7	1.6	1.6	1.6	1.6	1.6	1.6
TOTAL	-15.4	-5.2	-12.6	6.9	8.7	11.6	5.1	5.6	6.4
% LOAD REDUCTION	9.4%	24%	11%	10.4%	8.4%	6.6%	13.5%	12.5%	11%

differences have been computed in price tag 2.10.

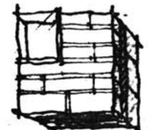
Average load differences have been used to calculate energy reductions. The load difference during worst conditions are multiplied by installation costs for the first cost reductions.

PRICE TAG 2.10

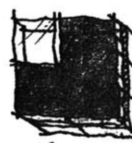
ADVANTAGE OF ONE FLOOR BELOW GRADE VS. ONE FLOOR ABOVE GRADE	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.9	.8	.8	.8	1.4	.9
5YR ENERGY	1.0	1.9	1.0	.4	1.0	.4
TOTAL	1.9	2.7	1.8	1.2	2.4	1.3

A subgrade wall in Boston is normally $1.00 per square foot less expensive to build because it lacks exterior finishes. The $1.00 per square foot reduction reduces project first costs 1%

CHART 2.8 - BELOW GRADE COMPARISON



APARTMENT BOSTON WORST CONDITIONS LOADS [ABOVE GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-35.4	-32.3	-34.5	7.7	9.5	12.2	5.9	6.4	7.2



APARTMENT BOSTON: WORST CONDITIONS LOADS [BELOW GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-12.8	-12.8	-12.8	1.6	1.6	1.6	1.6	1.6	1.6
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-31.6	-28.5	-30.7	6.9	8.7	11.4	5.1	5.6	6.4
LOAD DIFFERENCE	11%	12%	11%	10%	8%	7%	14%	13%	11%

but excavation increases first cost 2 1/2%.

Since forming below 8 feet of depth is economically prohibitive, the advantages of building below grade applies to only one fifth of the model 5 story building. 1/5 of all subgrade mechanical reductions are insignificant.

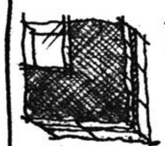
If a building is flattened into a one story subgrade building the larger roof surface would lose enough heat to off-set the advantages of building into the earth. Covering the roof with earth will increase structural costs tremendously.

Finally, only functions which do not require a view may be buried. If one side of a building is buried and the other left exposed only 1/2 of the

CHART 2.9 - BELOW GRADE OFFICE COMPARISON

1 SQ. FT.

BOSTON OFFICE AV. LOADS [ABOVE GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE LOADS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-14.1	-3.9	-11.3	22.8	24.6	27.3	21.0	21.5	22.3



1 SQ. FT.

BOSTON OFFICE AV. LOADS [BELOW GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-6.7	-6.7	-6.7	1.6	1.6	1.6	1.6	1.6	1.6
INFILTRATION	-19.0	-19.0	-19.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE LOADS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-12.5	-2.3	-9.7	22.0	23.8	26.5	20.2	20.7	21.5
LOAD DIFFERENCE	11%	41%	14%	4%	3%	3%	4%	4%	4%

mechanical advantages of tag 2.8 may be realized.

Burying a building into the constant temperature of the earth does not offer great mechanical advantages. Designers may bury buildings for many reasons, but the major reduction of mechanical costs should not be one of them.

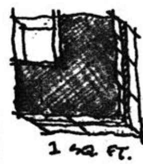
Price tag 2.11 lists the total 5 year cost of burying the first floor of the 5 story building.

PRICE TAG 2.11

ADVANTAGE OF BURYING ONE OF FIVE FLOORS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.2	.2	.2	.2	.3	.2
5YR ENERGY	.2	.4	.2	.1	.2	.1
TOTAL	.4	.5	.4	.2	.5	.3

CHART 2.10 - BELOW GRADE OFFICE WORST CONDITIONS

OFFICE WORST CONDITIONS [ABOVE GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-28.0	-28.0	-28.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	-31.4	-21.2	-28.6	22.8	24.6	27.3	21.0	21.5	22.3



OFFICE WORST CONDITIONS [BELOW GRADE]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-12.8	-12.8	-12.8	1.6	1.6	1.6	1.6	1.6	1.6
INFILTRATION	-28.0	-28.0	-28.0	5.4	5.4	5.4	5.4	5.4	5.4
OFFICE LOAD	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-28.2	-18.0	-25.4	22.0	23.8	26.5	20.2	20.7	21.5
LOAD DIFFERENCE	10%	15%	11%	4%	3%	3%	4%	4%	4%

Landscape and the Author's
Personal Aesthetic Guidelines

****

The guidelines developed in this section are subjective and personal. Lest important aesthetic concerns become subjected to energy objectives, aesthetic values related to the subject matter of this chapter will be listed and discussed.

If readers find this type of discussion useless, they are encouraged to proceed to the next mechanical section. I suggest the reading of these sections. They are brief and offer insights into the test design of the final chapter.

****

Landscaping and Natural Light

My intention is to use the richest natural lighting pallet within the limits of painful glare and pitch blackness. Some spaces should be cave-like and some should sparkle in dazzling light. A full range of lighting experiences should be available to each member of a family unit and to each member of a working unit. This lighting intention, however, should be limited by the following constraint. No function (living room, kitchen, coffee lounge, etc.) should be entirely grayed out or glared out.

Glare is defined as a light source that contrasts strongly with its surroundings or with the field form which it is viewed. Large patches of unobstructed sky always produce glare. I am not interested in eliminating glare (at times it is very beautiful), but merely to control its most relentless forms. Trees are useful in the control of relentless glare, because they intercept 50% of direct sun rays. Trees replace views of blank sky with their beautifully changing forms.

Indoor-Outdoor Connection

Each occupant of a housing unit or working group should have access to visual and physical contact to the surrounding landscape. This visual contact for me occurs when 1/3 of my cone of vision can be directed through a window to the landscape outside. Physical contact occurs when the exterior landscape moves into a building and a door is provided at that point.

Views

In each dwelling unit or work group, occupants must have access to short views, long views, and multi-directional views. Landscaping should be used to compose short views, and frame the longer ones.

HARD AND SOFT GUIDELINES

The mechanical reductions of this chapter are substantial only for special cases. When a large reflective building is built next door, for instance, heating costs drop considerably. The more reliable landscaping techniques like using trees for sun screening are found to have minor impact on mechanical economy.

It is for this reason that soft concerns have priority

CHART 2.11

HARD GUIDELINES

	APARTMENT 5 year energy savings	APARTMENT first cost savings	APARTMENT adjusted first cost savings	OFFICE 5 year energy savings	OFFICE first cost savings	OFFICE adjusted first cost savings*
USE DECIDUOUS TREES FOR SUNSCREENS	.2%	.3%	.5%	.3%	0%	.3%
BUILD 1 FLOOR BELOW GRADE	.2%	-.1%	.1%	.2%	0%	.2%
** USE WHITE GROUND COVER RATHER THAN GRASS. (REFLECTION TO ALL FIVE FLOORS.)	1.7%	0%	1.7%	.7%	0%	.7%
** AVOID OBJECTS WHICH COMPLETELY BLOCK BUILDING FROM DIRECT SUN	1.7%	0%	1.7%	1.8%	0%	1.8%
** SURROUND BUILDING WITH 80% REFLECTIVE OBJECTS	1.4%	0%	1.4%	1.0%	0%	1.0%

*Technique for including operation in first cost.
See Chapter I for explanation.

** IMPROBABLE SPECIAL CASES

in the following list of combined guidelines.

SOFT GUIDELINES

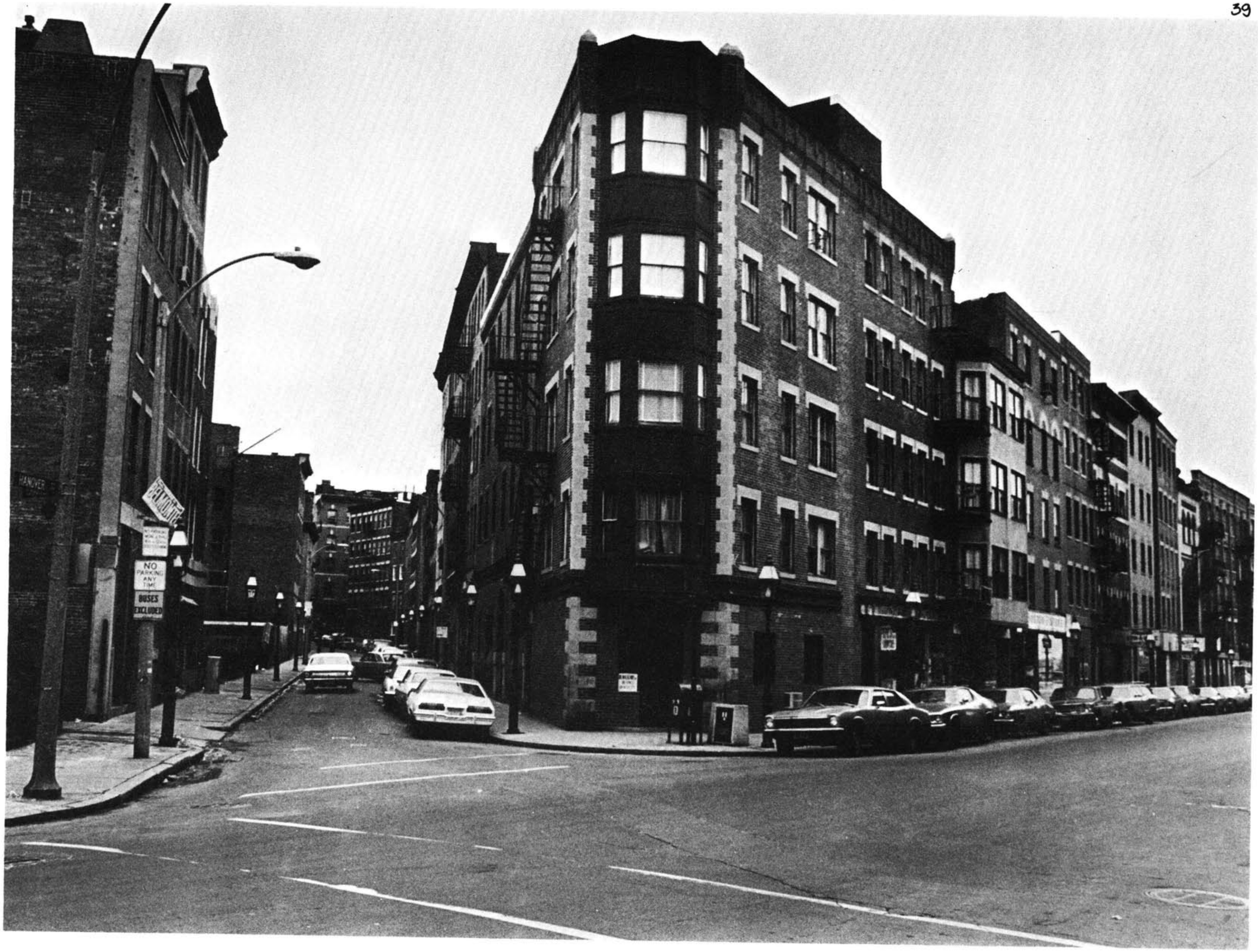
The following is an ordered list of soft guidelines for the use of landscaping:

1. Allow landscape to flow through walls where outdoor connection is desirable.
2. Use landscaping to compose short views and frame long views.
3. Screen natural light through deciduous trees and ivy.

Combined Guidelines

1. Allow landscape to flow through walls where outdoor connection is desirable.
2. Use landscaping to compose short views and frame long views.
3. Use deciduous trees for sun screens.
4. Screen natural light through deciduous trees and ivy.

3 SHAPE & ORIENTAT.



III. SHAPE AND ORIENTATION

III. Shape and Orientation

This chapter discusses the economics inherent in the overall shape and orientation of a structure. It will also deal with the human implications of these economic form generators.

This analysis will be presented in the following manner.

First: I will identify what I consider to be the full set of issues that relate the shape and orientation of a building to its first cost and operation cost.

Second: I will propose the proper methods of measuring the relative importance of these issues.

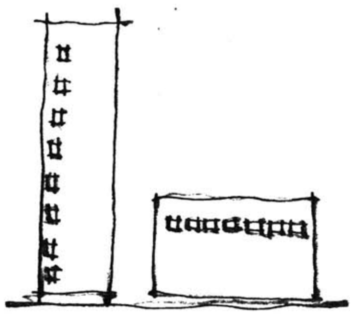
Third: I will analyze the human impact of decisions involving manipulations of a building's shape and direction.

Fourth: Finally, I will combine my economic and human objectives in one list of guidelines.

A. COST ISSUES

The following is the list of issues which relate shape and orientation to mechanical costs.

1) Shape



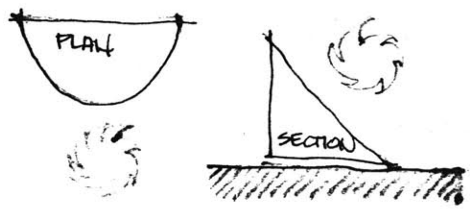
All the heat which a building loses goes through its skin. The smaller its skin, the smaller the mechanical systems and energy bills. Besides the reductions in mechanical systems, a smaller surface offers considerable savings in materials and labor.

Shape and Lighting

Electric lighting costs increase with the depth of a building.

2) Orientation

The heat flowing from the sun can be more effectively received by a building facing the sun in both plan and section.

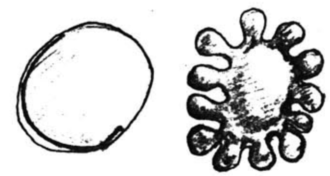


Orientation and Lighting

Lighting levels vary in intensity for different orientations on clear days, but during worst conditions (heavy clouds) all orientations receive identical amounts of natural light.

The relationship of orientation to lighting installations is not an issue.

3) Crenelation*



The carving of a building's exterior into patterns of solid and void has three economic implications.

- Additional surface material increases initial construction costs.
- The first and operating costs of heating and cooling are increased proportionally with the amount of additional skin area.
- Natural lighting may be increased when cavities are cut into building volume.

*Tessellation; bumps; surface deformation.

MODELS AND MEASUREMENT

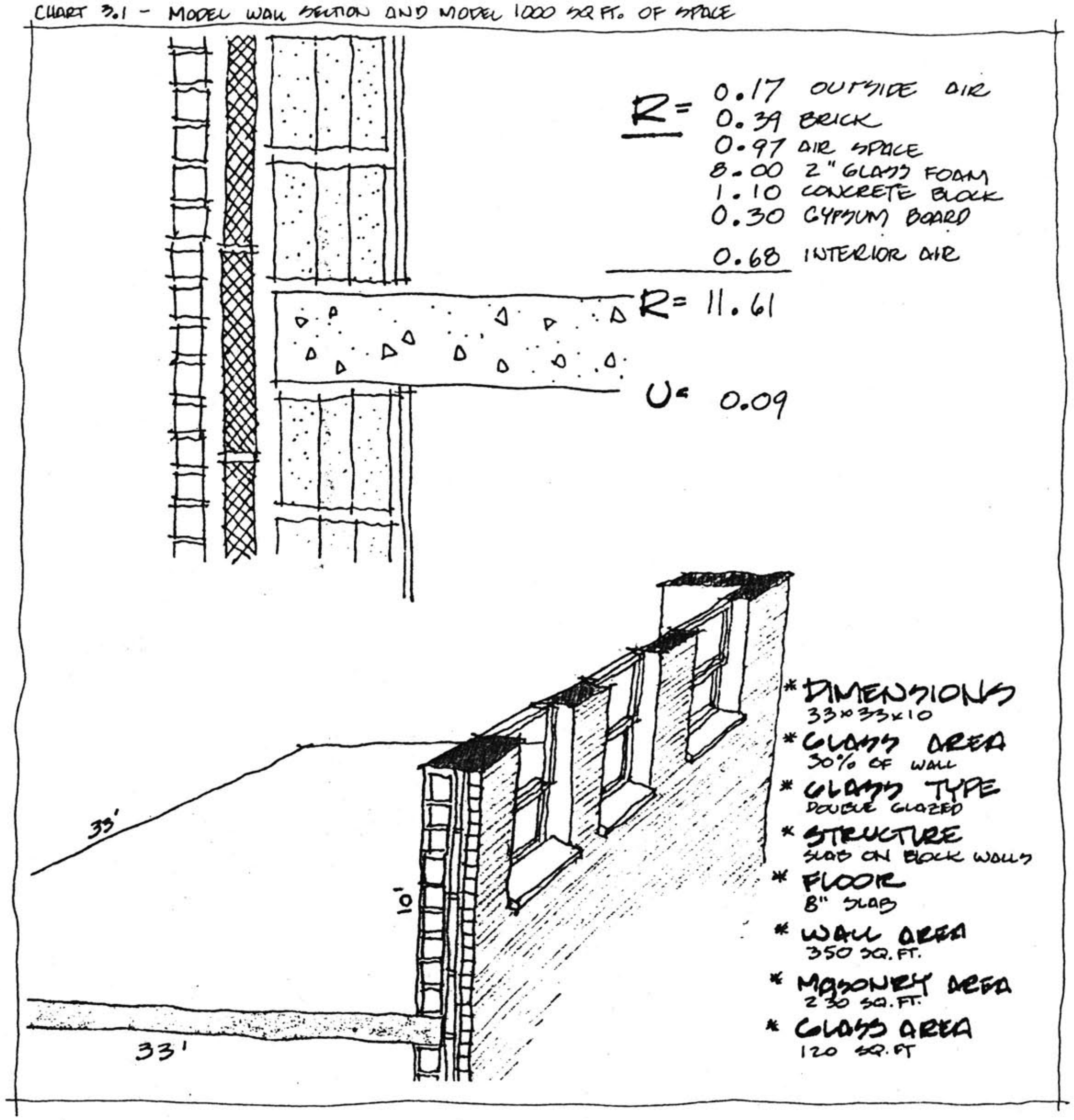
In this section, equations and models are proposed for the proper measurement of the value of each of the preceding issues.

Shape, Labor and Material Costs

The model used in this report is a $35 per square foot building with enclosing walls costing $6 per square foot. Walls in this case account for about 20% of a building's first cost.

When an architect uses twice the material to enclose the same square footage he increases the first cost of his building by 17%. (1.7 million on a 10 million dollar building.)

CHART 3.1 - MODEL WALL SECTION AND MODEL 1000 SQ FT. OF SPACE



PRICE TAG 3.1

MATERIAL AND LABOR COST OF DOUBLING SURFACE AREA	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	17%	17%
5YR ENERGY	—	—
TOTAL	17%	17%

CHART 3.2 – ASHRAE SUNCHART.

SOLAR HEAT GAIN FACTORS FOR 40°N LATITUDE, WHOLE DAY TOTALS
Btu/ft²/day (Values for 21st of each month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	118	162	224	306	406	484*	422	322	232	166	122	98
NNE	123	200	300	400	550	700*	550	400	300	200	123	100
NE	127	225	422	654	813	894*	821	656	416	226	132	103
ENE	265	439	691	911	1043	1108*	1041	903	666	431	260	205
E	508	715	961	1115	1173	1200*†	1163	1090	920	694	504	430
ESE	828	1041	1182	1218*†	1191†	1179	1175†	1188†	1131	971	815	748
SE	1174	1285	1318*	1199	1068	1007	1047	1163	1266	1234	1151	1104
SSE	1490	1509*	1376	1081	848	761	831	1049	1326	1454	1462	1430
S	1630*†	1626†	1384†	978	712	622	694	942	1344†	1566†	1596†	1482†
SSW	1490	1509*	1370	1081	848	761	831	1049	1326	1454	1462	1430
SW	1174	1285	1318*	1199	1068	1007	1047	1163	1266	1234	1151	1104
WSW	828	1011	1182	1218*†	1191†	1179	1175†	1188†	1131	971	815	748
W	508	715	961	1115	1173	1200*†	1163	1090	920	694	504	430
WNW	265	439	691	911	1043	1108*	1041	903	666	431	260	205
NW	127	225	422	658	813	894*	821	656	416	226	132	103
NNW	123	200	300	400	550	700*	550	400	300	200	123	100
HOR	706	1092	1528	1924	2166	2242*	2148	1890	1476	1070	706	564

*month of highest gain for given orientation(s)
†orientation(s) of highest gain in given month

SOURCE: ASHRAE, *Handbook of Fundamentals*, 1970, Koolshade Corporation.

Shape, Heating and Cooling

The equipment needed to measure the effects of a 'building shape' on heating and cooling is: The ASHRAE Average Sun Table, one right forefinger, and the basic heat loss equation.

All residential heating and cooling loads go through a building's walls. If the wall area is doubled, heating and cooling loads double.

PRICE TAG 3.2

THE EFFECT OF HALVING SURFACE AREA ON RESIDENTIAL HEATING AND COOLING	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	4.0	
5 YR ENERGY	5.1	
TOTAL	9.1	

Shape and Office Heating and Cooling

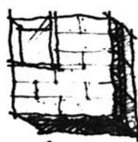
Office mechanical costs are more complicated to calculate because not all heating and cooling loads flow through the weatherskin. Additional loads are produced by machines, lights, people, and mechanical ventilation.

Chart 3.3 has been constructed to compare average loads on offices of the same volume but with surface areas that differ in the ratio of 2 to 1. These average loads may be compared to determine energy savings.

CHART 3.3 - COMPARISON OF LOADS ON SAME VOLUME WITH DOUBLED SURFACE AREA

1 SQ. FT.

AV. OFFICE HEATING AND COOLING LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
1/2 SURFACE AREA	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS (BTU/HR)	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-11.9	-11.9	-11.9	.8	.8	.8	.8	.8	.8
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-7.0	3.2	-4.1	18.2	20.0	22.7	16.4	16.9	17.7



1 SQ. FT.

AV. OFFICE HEATING AND COOLING	WINTER			SUMMER UNSHADED			SUMMER SHADED		
FULL SURFACE AREA	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	1.6	22.0	7.2	5.2	8.8	14.2	1.6	2.6	4.2
HEAT LOSS	-16.6	-16.6	-16.6	4.8	4.8	4.8	4.8	4.8	4.8
INFILTRATION	-15.8	-15.8	-15.8	1.1	1.1	1.1	1.1	1.1	1.1
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-18.4	2	-12.8	23.5	27.1	32.5	19.9	20.9	22.5

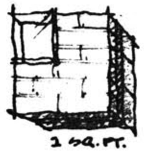
Chart 3.4 shows the load differences under worst conditions. Since worst conditions dictate mechanical capacities, these loads are used to calculate reductions in first costs.

Price tag 3.3 lists the total reductions produced by halving an office building's surface area.

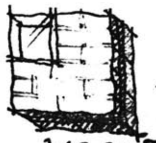
PRICE TAG 3.3

HEATING AND COOLING ADVANTAGE OF HALVING OFFICE SURFACE AREA	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				3.8	4.3	4.2
5YR ENERGY				2.2	0	2.4
TOTAL				6.0	4.3	6.6

CHART 3.4 - WORST CONDITIONS LOADS

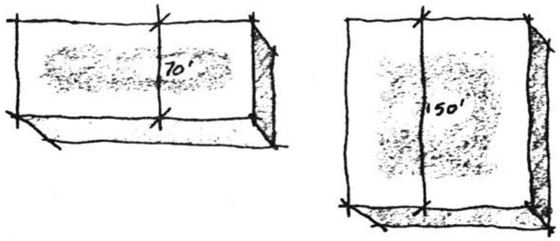


OFFICE HEATING AND COOLING 1 SQ. FT. [1/2 SURFACE AREA]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-23.0	-19.9	-22.1	20.1	21.9	24.6	18.3	18.8	19.6



" 1 SQ. FT. [FULL SURFACE AREA]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.4	6.6	2.2	5.2	8.8	14.2	1.6	2.6	4.2
HEAT LOSS	-33.2	-33.2	-33.2	4.8	4.8	4.8	4.8	4.8	4.8
INFILTRATION	-28.5	-28.5	-28.5	4.1	4.1	4.1	4.1	4.1	4.1
OFFICE GAINS	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
TOTAL	-48.9	-42.7	-47.1	26.5	30.1	35.5	22.9	23.9	25.5
LOAD DIFFERENCE	53%	53%	53%	24%	27%	31%	20%	21%	23%

Lighting Correction



If the building with twice the surface area has a 70 foot section, as opposed to a 150 foot deep section in the more compact building, more of its interior may be lit with sunlight.

Natural light is a valuable commodity for office buildings, because lighting accounts for 50% of energy costs. Since a greater proportion of a narrow building can be naturally lit, a narrow office will have appreciably lower electric bills. 20% of a 70 foot deep building can be naturally lit through most of the working day, while only 10% of the deeper building may be similarly lit. The 10% lighting cost difference represents a 5% reduction in office energy requirements. Unless circumstances forbid evening office work, no reduction in lighting installations could be achieved by reducing a building's width.

PRICE TAG 3.4

LIGHTING ADVANTAGE OF A 70 FT DEEP OFFICE OVER A 150 FT DEEP OFFICE	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST						
5 YR ENERGY				.7	.7	.7
TOTAL				.7	.7	.7

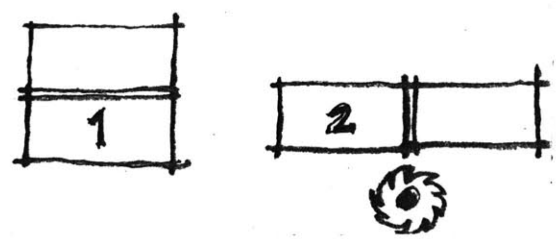
Shape Conclusions

Price tag 3.5 totals the preceding 'shape cost reductions.' These total percentages were obtained by multiplying the proportions of a building's cost required for mechanical equipment and 5 years of energy by the load reductions possible area.

PRICE TAG 3.5

ADVANTAGE OF HALVING SURFACE AREA	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	21	21	21	21.1	21.1	21.1
5 YR ENERGY	5.1	5.1	5.1	1.5	-.7	1.7
TOTAL	26.1	26.1	26.1	22.6	20.4	22.8

Orientations and Shape



My purpose here is to discover which is more desirable from the heating standpoint: a compact building or a building strung out before the southern sun. My method of evaluation will again involve only: the simple heat loss equation and the ASHRAE sun chart.

Assume now that Buildings 1 and 2 in the above illustrations have floor areas of 1 square foot.

On an average winter day, Building 1 gains 6 BTUH from the sun while losing 20 through its walls. Building 2 with its larger southern exposure gains 8.4 BTUH but loses 28 because of its greater surface.

The more compact building has a lower operating cost by 2%. Increasing the proportion of glass in the south wall of Building 2 will only

ciency.

Worst winter conditions dictate the size of heating equipment. Worst conditions take place at 3 AM on the coldest of winter nights when no added sunshine can decrease the heating loads of Building 2. Building 2 will have a 25% greater maximum load because of its 25% greater surface.

The price tag below indicates that the most efficient shape for a Boston building is the most compact.

PRICE 3.6

ADVANTAGE OF COMPACT PLAN OVER ELONGATED SOUTH ORIENTATION [BLDG. 1 VS. BLDG. 2]	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	6.2	8.0
5 YR ENERGY	.2	.2
TOTAL	6.4	8.2

Plan Orientation of Compact Shapes

Two aspects of compact plan shapes are investigated: the relationship between different geometric plan shapes and mechanical costs; and the effect of rotating a square plan 45°.

Sun and Plan Shape

Winter sun reaches the proportion of a building's surface shown in the illustrations on the top of the next page. Summer sun proportions are shown below.

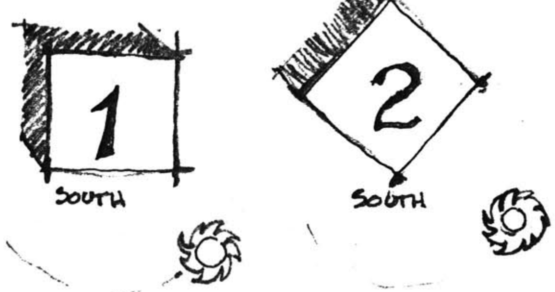
From inspection it is obvious that greater amounts of sun are received by various basic shapes.

Checking this observation through sun charts, it is found for example, that 30% more winter sun is received by plan e than plan b. Though not staggering, considerable energy and first cost savings are made possible by choosing an efficient plan shape.

PRICE TAG 3.7

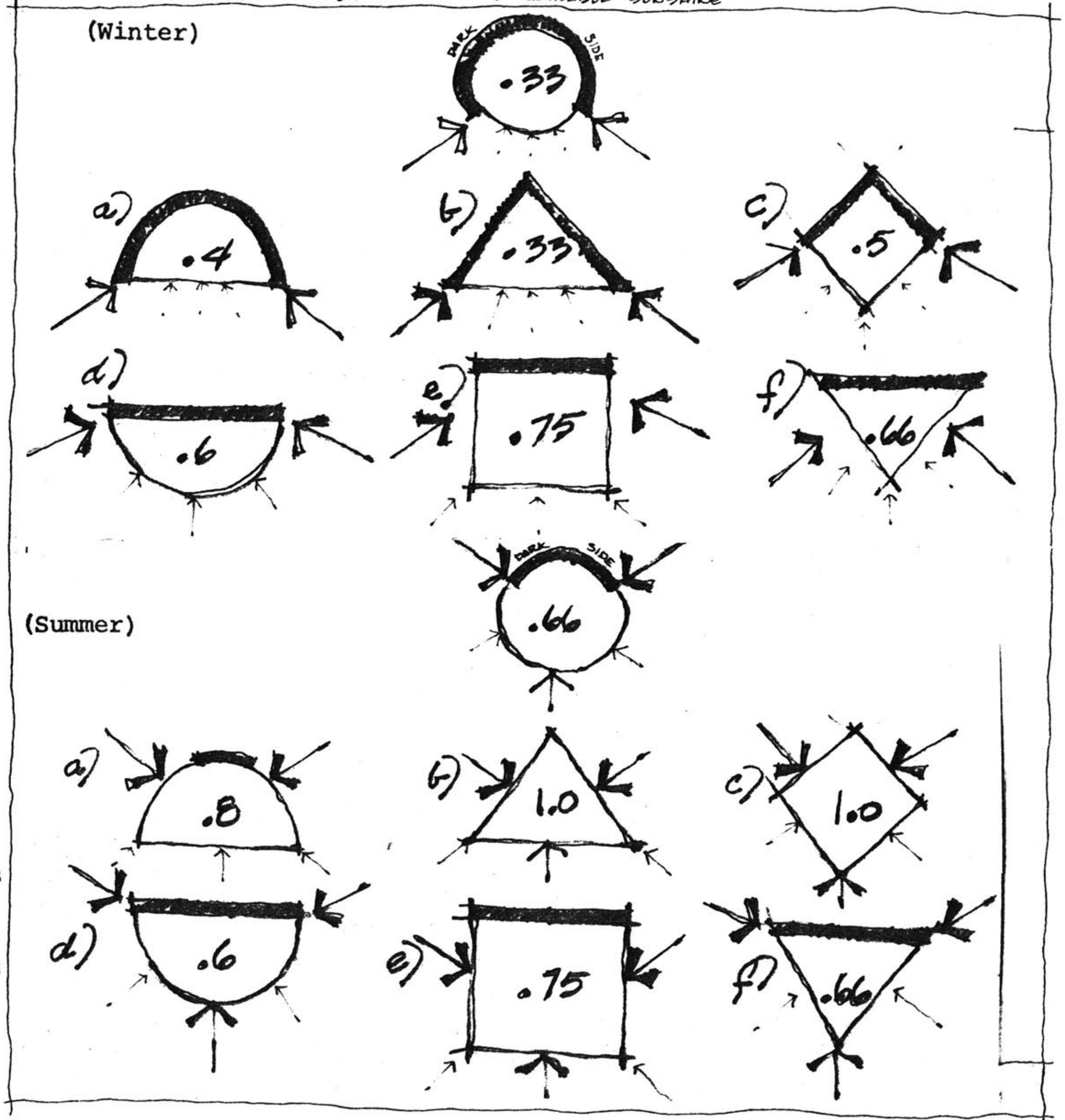
ADVANTAGE OF PLAN [e] VS. PLAN [b]	% COST REDUCTION	
	APARTMENT	OFFICE
1^{ST} COST	1.7	1.7
5^{YR} ENERGY	.7	1.5
TOTAL	2.4	3.2

45° Rotation



Building 1 aligns with compass coordinates while 2 is as nearly opposite as is possible, and aligns diagonally across longitudinal lines.

CHART 3.5 - GEOMETRIC PLAN SHAPES AND AVAILABLE SUNSHINE



In New England the average surface of Building 1 received 14.2 BTU's per square foot of glass per hour during the heating season and 37.5 BTUH during cooling season. Building 2 receives approximately 13.8 BTU's per square foot per hour in heating season and 35 BTU's per square foot per hour during cooling season.

The .4 BTUH per square foot heating season advantage of 1 over 2 represents a .5% energy reduction for housing, and .25% for offices.[2] On the other hand, the 10 BTUH per square foot cooling season advantage of 2 over 1 represents a 3% energy reduction for housing, and a .3% energy reduction for offices.

Chart 3.6 shows the first and operating costs of spinning a square building 45°.

The price tag below shows that rotating a square building 45° does not affect mechanical costs.

CHART 3.6

ADVANTAGE OF: PLAN e VS. PLAN b	HOUSING: OPERATION %	HOUSING: FIRST COST %	OFFICE: FIRST COST %	OFFICE: OPERATION %
HEATING	4	.5	1.5	3
COOLING (UNSHADED) SUMMER	-2	-.2	-.6	-1
TOTAL (UNSHADED) SUMMER	2	.3	1	2
TOTAL (SHADED) SUMMER	4	.5	1.5	3

[2] 70 foot deep section

PLAN □ vs. PLAN ◇ (NORTH)	% COST REDUCTION: APARTMENT	% COST REDUCTION: OFFICE
1ST COST	0	0
5 YR ENERGY	-.3	0
TOTAL	-.3	0

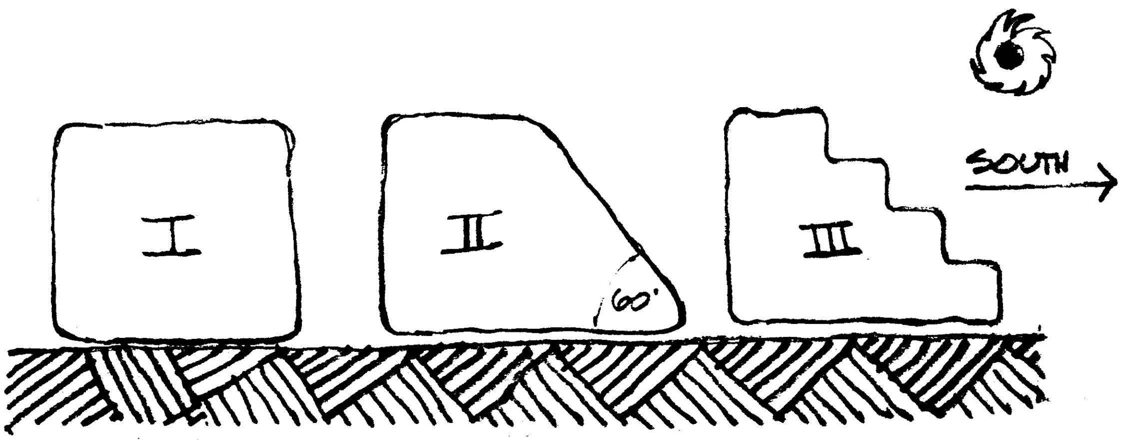
Orientation in Section

The object of this discussion will be to determine the amount that a building's first and operating costs may be altered by warping its section into the direct rays of winter sunshine.

The means of calculation will again be the ASHRAE tables of average sun gains and the basic heat loss equation.

CHART 3.7

ADVANTAGE OF: PLAN □ VS. PLAN ◇	HOUSING: OPERATION %	HOUSING: FIRST COST %	OFFICE: FIRST COST %	OFFICE: OPERATION %
HEATING	.5	0	0	.25
COOLING [WINDOWS UNSHADED]	-3	0	0	-.3
TOTAL	-2.5	0	0	0



Section Orientation and Heating

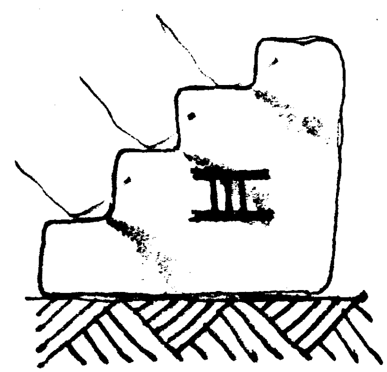
The 3 building sections shown above contain equal volumes. Buildings I and II have the same above grade surface area and the same heat loss. Because Building III has 10% more surface area above grade, it has a 2% greater construction cost as well as a 10% greater heat loss.

Building II receives 20% more winter sunshine than the conventional Building I, and Building III receives 25% more than I. 20% and 25% more sunshine on the model wall will decrease heating loads by 10%, and 12% for apartments and 25% and 30% for offices.

The final 'heating' results of warping a building section to face the winter sunshine, as shown in my two examples, would be the following: in apartment buildings, section II affords a 6% operation savings over I. In office buildings operation costs are reduced 4%.

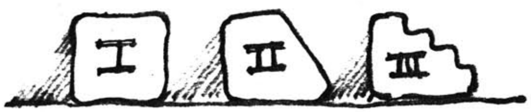
III provides a -3% operating and -1% first cost savings in apartments and a -8% operating and -2% first cost savings in offices.

Office Lighting



60% more natural lighting enters building III than enters building I. In a 70 foot deep office, 7% of an energy bill may be eliminated by the lighting savings created by the reflecting 'steps'.

Summer Overload



If unshaded from summer sunshine, II represents a 10% increase in cooling loads for apartments and 6% for offices. Energy consumption would rise 3% for apartments and 2% for offices.

If the southern glazing is not shaded from the summer sun, no energy or equipment reductions are attainable by the warping of a building section.

'Section Orientation' Conclusions

Chart 3.8 breaks down the costs of the 2 warped sections, and price tags 3.8 and 3.9 show total reductions translated into 1st. costs.

PRICE TAG 3.8

SECTION VS. SECTION	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	0	0
5YR ENERGY	.3	.3
TOTAL	.3	.3

PRICE TAG 3.9

SECTION VS. SECTION	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	-1.0	-2
5YR ENERGY	-1.1	.4
TOTAL	-2.1	-1.6

Section Orientation and Glass Area

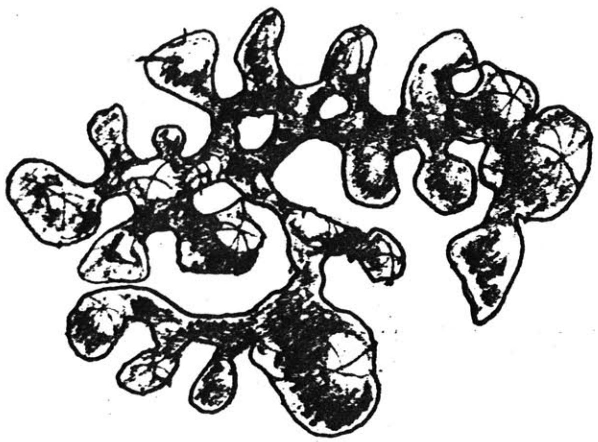
If glass were to fill twice as much of the south wall (60%), twice as much sun heat could be collected, but the loss through that same 60% glass wall would be 2 times the possible gain. Now, however, the difference is a larger number. Even if the windows were covered with fully insulated panels at night, the 60% glass wall facing south and located in New England would be a greater loser than the 30% glass wall left uncovered.

Crenelation

Crenelation is considered by many to be the stuff of architecture. It's the ins, the outs, the zigs and zags, the bumps and decoration.

The purpose of this next section is to project the cost of these wall deformations.

The tools needed for these calculations are: chart 1.1 which lists building cost proportions, ASHRAE'S sunshine chart, and the heat loss equation.



Crenelation and Heating

Double a building's surface area and you double its heat load. This alone would increase yearly energy demands by 30% for housing and 10% for offices. The first cost increases due to the increased heating loads would be 3% for housing and 2.5% for offices.

CHART 3.8 - WARPED SECTIONS

ADVANTAGES OF WARPED SECTIONS VS CONVENTIONAL SECTION	% COST REDUCTION — APARTMENT: OPERATION	APARTMENT: FIRST COST	OFFICE: FIRST COST	OFFICE: OPERATION
II HEATING	6	0	0	4
II COOLING	-3	0	0	-2
II COMBINED	3	0	0	2
III HEATING	-3	-1	-2	-8
III COOLING	-7	0	0	-4
III LIGHTING	0	0	0	15
III COMBINED	-10	-1	-2	3

* SUMMER SUN SHADE ASSUMED

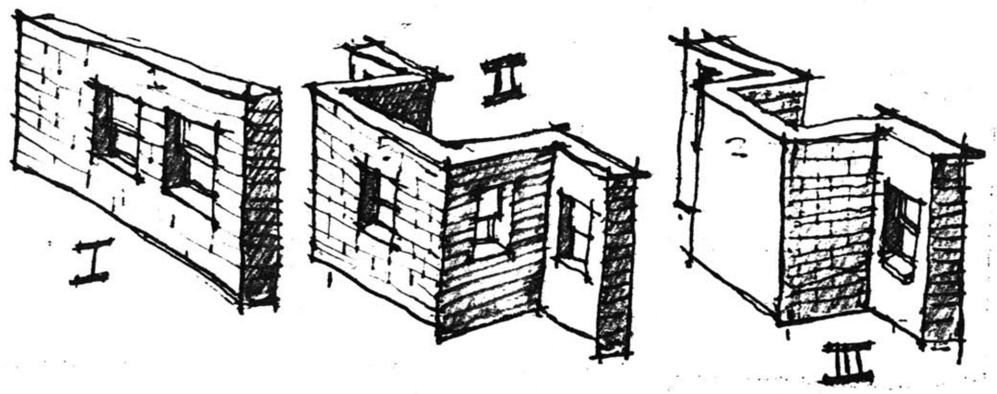
Crenelation and Cooling

For apartment buildings, the doubling of a building's surface area would provide a 20% increase in yearly energy consumption due to added air conditioning costs. A.C. first cost increase due to added surface area would be 2% for apartments.

In offices, only about 15% of the cooling load comes through the wall; the rest is internally produced by lights, people, and machines.

Therefore, doubling the surface only increases office energy bills 4% due to additional cooling cost. Total project cost would be increased 1%.

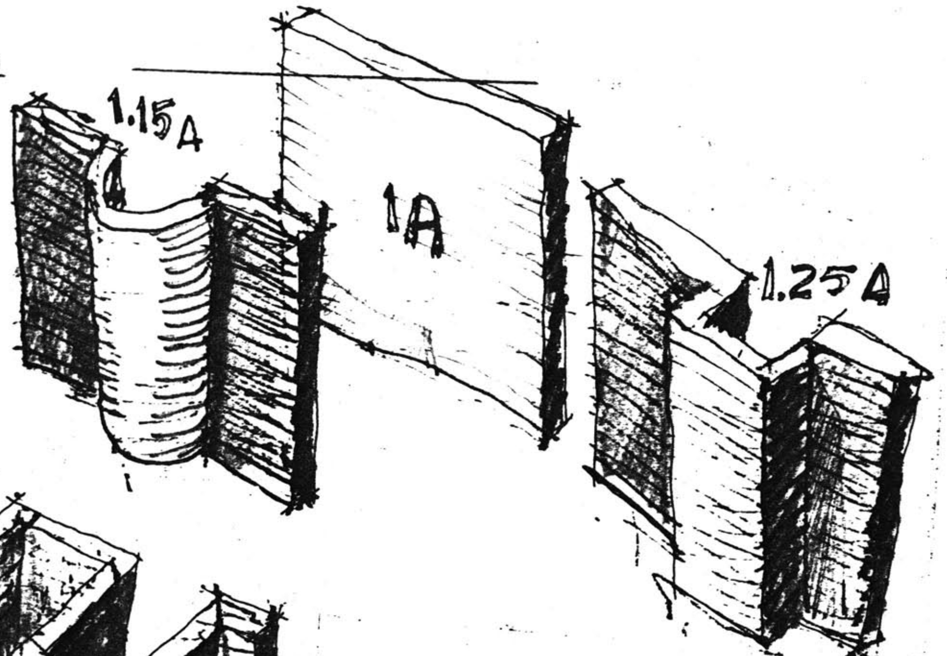
Discounting Windows

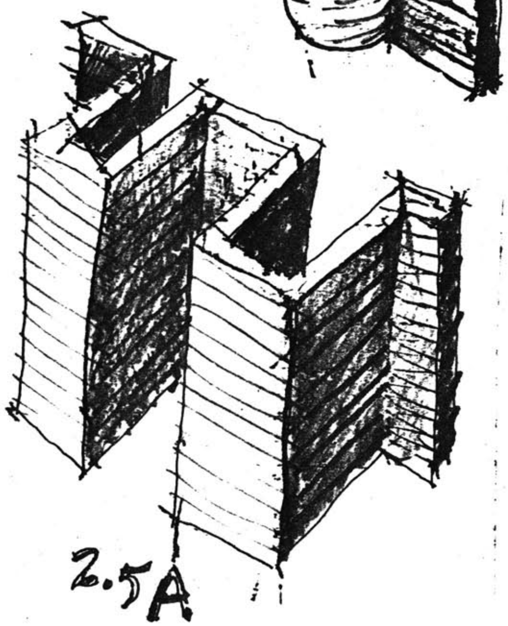


One third of the heat loss of a 30% glass building escapes through the opaque portion of the wall. If wall area is doubled without increasing window area (Example III) only a 20% heat load increase results.

This would increase apartment energy bills 10% and office bills 5%. First costs would increase 1% in apartments and 1.3% in offices.

Wall Costs





In an average 5 story 100,000 square foot building, wall costs are about 20% of a total project's cost. Double a building's surface area and a project's cost jumps 17%.

Crenelation Conclusions

PRICE TAG 3.10

ADVANTAGE OF A BUILDING WITH 1/2 SURFACE AREA	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	21.1	21.1
5YR ENERGY	5.1	1.5
TOTAL	26.1	22.6

PERSONAL GUIDELINES

The guidelines developed in this selection are subjective and personal. Lest important aesthetic concerns become completely subjected to energy objectives, aesthetic values related to the subject matter of this chapter will be listed and discussed.

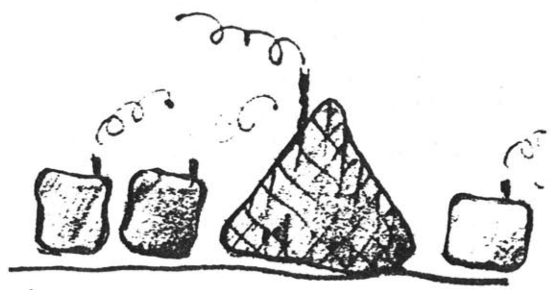
If a reader finds this type of discussion useless s(he) is encouraged to proceed to the next mechanical section. The author suggests the reading of these sections. They are brief and offer insights into the test design of the final chapter.

Shape and Natural Light

Contact distance, the distance from a window wall after which this occupant no longer feels any sensation of natural light, is approximately 30 feet in normal spaces with 8 foot ceilings and 4 foot windows. Floor to ceiling glass push that distance back to perhaps 40 feet. A person's working or living space must never be beyond contact distance.

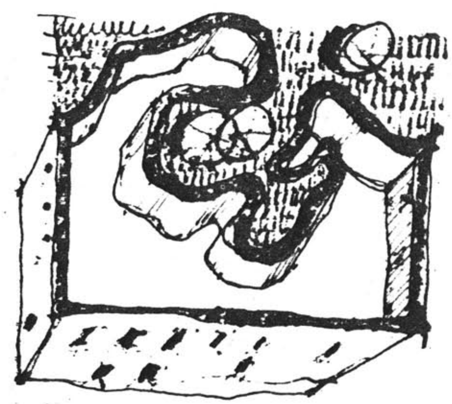
Comfortable reading can take place up to 10 feet from a 4 foot window in a room of normal reflectance. Overhead windows are effective at twice that distance. It is important that reading by natural light be possible in all living and working space.

Shape and Appearance



An architect must determine whether a building will stand apart from its surroundings or blend into its 'landscape'. Inside the building, again the architect must design to allow an occupant to feel part of a neighborhood, or part of a 'special place'.

Shape and Outdoor Connections



This occupant becomes well aware of the outside world when about 30% of his cone of vision can be filled with a view outside. Because most people enjoy some outside contact, it's important that an architect keep people in the outermost 30 feet of a building.

Maximization of an occupant's feeling of possession

and control over an outside area should be an architect's objective.

The wall line between outside and inside should become blurred where contact is desired.

Shape and Views

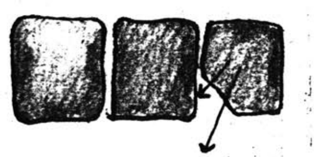
For every living or working group some long, some short and some multi-directional views should be provided.

A single view through a flat plane of glass, with no balcony, nor any part of the building's exterior visible, is to be considered insufficient.

Orientation and Appearance

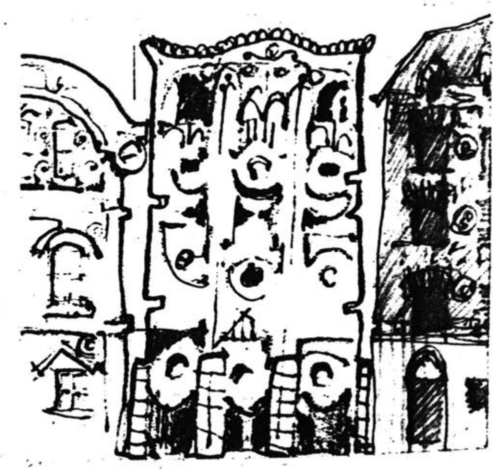
The architect must determine the formal order of an immediate landscape and then either play off or work with that order.

Orientation and Views



In order to develop long and short views it is often helpful to orient a building into an adjoining building.

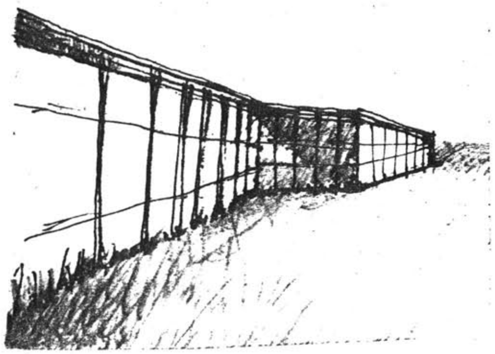
Crenelation and Appearance



Crenelations are bumps and textures which decorate a building. These crenelations may be as large as a building wing or as small as a doorknob.

The important issue for the architect is: Is the existing appearance of a proposed building's neighborhood worth reinforcement?

Crenelation and Outdoor Connections



The architect may perforate and corrugate building edges to allow the outside world in. He may also build solid planes that mark a distinct boundary.

Views and Lifestyle

The convolutions of a building skin are ideal for developing interesting short views. These surface pockets are places where outdoor guardianship and living can comfortably take place.

Personal Objectives

The following is the author's ordered list of personal aesthetic objectives which pertain to building shape and orientation:

SOFT GUIDELINES

1. Provide natural light 'contact' for every living or working space.
2. Choose shape, orientation and crenelation for desired relationship between building and neighborhood.
3. Use shape to include or exclude outside space.
4. Vary views:
   - long
   - short
   - multi-directional

HARD GUIDELINES

CHART 3.9

OBJECTIVES	APARTMENT 5 year energy savings	first cost savings	adjusted first cost savings	OFFICE 5 year energy savings	first cost savings	adjusted first cost savings*
HALF CRENELATION	5.1	21.0	26.1	1.5	21.1	22.6
HALF SHAPE	5.1	21.0	26.1	1.0	21.1	22.1
CRENELATE WALLS ONLY (WHEN DOUBLING SURFACE AREA)	10.0	1.0	1.5	5.0	2.0	2.0
CHOOSE PLAN GEOMETRY	.7	1.7	2.4	1.5	1.7	3.2
WARP SECTION TO WINTER SUN	.3	0	.3	.3	0	.3

*Technique for including operation in first cost.
See Chapter I for explanation.

COMBINED GUIDELINES

This is the author's list showing where he feels the soft guidelines must stand among the hard. For every architect there should be a different set, but there must be a combined understanding.

1. Contact people with natural light;
2. Minimize crenelation;
3. Build deliberately for or against existing context (shape, orientation, crenelation);
4. Simplify and maximize building shape;
5. Entrain or expell surrounding landscape;
6. Crenelate walls, not windows;
7. Provide long, short, and multi-directional views;
8. Warp section to winter sun.

4 WINDOWS

COST ISSUES

A complete set of 'economic issues' is listed below. All are interrelated, and addressed in the order listed.

Issue #1: Window Area

The most economical amount of window must be determined.

Issue #2: Window Glass

The proper number of glass layers must be determined. Special reflective and heat absorbing glass must be evaluated for their appropriate use.

Issue #3: Window Shading

The value of screening windows from summer sun must be calculated.

Issue #4: Window Covers

The economic impact of insulating window covers must be quantified.

MODEL AND MEASUREMENTS

The same 1000 square feet of space used throughout this report will again serve as a model.

The method of evaluation is the comparative analysis of the 'wall charts' which have been constructed for display in the following pages. Some of these charts deal with average temperatures and may be used to compare energy consumption. Others present peak loads under worst conditions and are used to determine installation capacity.

All of the numbers in the wall charts are either well-known 'book values' or the products of simple calculations.

*Average Sun Gains are charted in dozens of publications.[1]

*Heat Loss is the product of a wall's conductance (book value) and the difference between the temperatures it divides.

*Infiltration is the amount of heat required to warm or cool replacement air which leaks through skin cracks or is mechanically exhausted. In the assumed model, 1/2 of the room's air must be replaced per hour in apartments. Office space will require a full air change.

*Sun Waste is the amount of extra sun heat which would overheat a winter room and would have to be exhausted. In this model the building's mass has

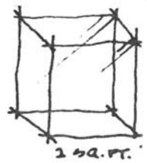
[1] ASHRAE Handbook of Fundamentals is used for this report.

more heat storage capacity than average daily sunheat. Therefore no sunheat is presumed to be wasted.

WINDOW AREA

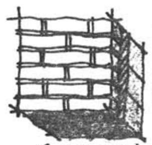
A comparison of 'wall charts' 4.1 and 4.2 points out only one case in which a square foot of glass operates more economically than a square foot of wall. South-facing glass appears to be 'making energy' during average daily operation. Real situations, however, often bring enough consecutive cloudy days to deplete all 'structure stored' heat. It is because of these worst conditions that mechanical equipment is designed to handle all heating without help from the sun. The entirely glass, south-

CHART 4.1 – DOUBLE GLASS VS. MASONRY



BOSTON: AVE. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
[DOUBLE GLASS]	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	2.7	36.7	11.9	8.6	14.5	23.8	2.6	7.8	13.2
SUN WASTE	0	0	0						
HEAT LOSS	-21.0	-21.0	-21.1	6.0	6.0	6.0	6.0	6.0	6.0
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-27.8	6.2	-21.9	17.3	23.2	32.5	11.3	16.5	21.9

CHART 4.2 – INSULATED MASONRY



BOSTON: AVE CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
[INSULATED WALL]	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	0	0	0	0	0	0			
SUN WASTE	0	0	0	0	0	0			
HEAT LOSS	-2.8	-2.8	-2.8	.8	.8	.8			
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7			
TOTAL	-12.3	-12.3	-12.3	3.5	3.5	3.5			

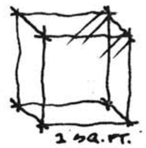
+ AV. ΔT = 35°F IN WINTER, 10°F IN SUMMER

+ U VALUE FOR DOUBLE GLASS: .6, FOR MASONRY WALL: .08

facing wall would require three times the mechanical equipment and therefore would be approximately one-third as economical. Charts 4.3 and 4.4 show this first cost relationship on the following page.

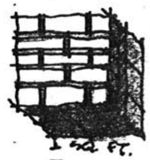
A square foot of double glass facing any direction in Boston could be more economically replaced by a square foot of insulated masonry wall. The best window area for a Boston wall is the smallest area which can accommodate human needs. A wall comprised of 30% window and 70% insulated masonry is the author's best guess at proper proportions. Wall charts 4.5 and 4.6 present the climate related loads on a 30% window wall.

CHART 4.3 — DOUBLE GLASS VS. MASONRY WALL : WORST CONDITIONS



BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
1 SQ. FT. [DOUBLE GLASS]	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	0	0	0	8.6	14.5	23.8	2.6	7.8	13.2
SUN WASTE	0	0	0						
HEAT LOSS	-42	-42	-42	6.0	6.0	6.0	6.0	6.0	6.0
INFILTRATION	-19	-19	-19	2.7	2.7	2.7	2.7	2.7	2.7
	-61	-61	-61	17.3	23.2	32.5	11.3	16.5	21.9

CHART 4.4 — DOUBLE GLASS VS. MASONRY WALL



BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
1 SQ. FT. [INSULATED WALL]	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	0	0	0	0	0	0			
SUN WASTE	0	0	0	0	0	0			
HEAT LOSS	-5.6	-5.6	-5.6	.8	.8	.8			
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7			
	-24.6	-24.6	-24.6	3.5	3.5	3.5			

+ DESIGN TEMPERATURES: WINTER 0°F , SUMMER 85°F

MODEL CHECK

Double glass was assumed while searching for an optimal window area. That assumption may be tested by exploring other glass types for some thermal advantage.

COMMON ALTERATIONS

Single, triple, and specially treated glass are analyzed in charts 4.7 and 4.13. These different glass types are found to have no special features which would enlarge the optimal window area, but to have advantages and disadvantages of their own.

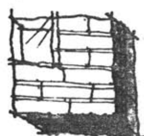
SINGLE GLASS

Because single glass loses

CHART 4.5 — 30% GLASS WALL: AV LOADS

BOSTON: AV. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2

CHART 4.6 — 30% GLASS WALL : WORST LOADS



BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-35.4	-32.3	-34.5	7.7	9.5	12.2	5.9	6.4	7.2

† AV. ΔT = 35°F WINTER, 10°F SUMMER

† WORST CASE ΔT = 70°F WINTER, 10°F SUMMER

more heat in winter and gains more in summer, it could not possibly increase the 30% glass-to-wall area unless its lower first cost offers greater savings than its operating disadvantages.

Single glass is presently about $3 cheaper than double glass per square foot of window. The cost advantage of using single over double glass is about $.30 per square foot of floor space or.9% of overall construction costs. This apparent economy is completely outweighed by 5 years of energy costs plus the necessary installation of a larger mechanical system.

The tag below shows these savings are fairly constant in all directions, but that they are about 1/2 as significant in offices which are less affected because they

CHART 4.7 - SINGLE GLASS : AV. LOADS

1 SQ. FT.

BOSTON: AVE. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.9	12.1	4.0	2.9	4.8	7.8	.9	1.4	2.3
SUN WASTE	0	0	0						
HEAT LOSS (U=1.1)	-13.6	-13.6	-13.6	3.3	3.3	3.3	3.3	3.3	3.3
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-22.2	-11.0	-19.1	8.9	10.8	13.8	6.9	7.4	8.3

CHART 4.8 - SINGLE GLASS : WORST LOADS

1 SQ. FT.

BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.3	3.6	1.2	2.9	4.8	7.8	.9	1.4	2.3
SUN WASTE	0	0	0						
HEAT LOSS	-27.2	-27.2	-27.2	3.3	3.3	3.3	3.3	3.3	3.3
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-45.9	-42.6	-45.0	8.9	10.8	13.8	6.9	7.4	8.3

require twice as many air changes.

Single glass is not recommended for any permanent building in the Boston area.

PRICE TAG 4.1

1 LAYER GLASS vs. DOUBLE GLASS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	-2.4	-2.4	-2.4	-2.9	-2.9	-3.3
5YR ENERGY	-4.7	-7.3	-4.4	-.9	-1.2	-1.0
TOTAL	-7.1	-9.7	-6.8	-3.8	-4.1	-4.3

TRIPLE GLASS

The use of triple glass in the model wall is more economical than double glass. Triple glass even allows a slight expansion of south-facing glass area without increasing cost.

CHART 4.9 – TRIPLE GLASS: AV. LOAD

1 SQ. FT.

BOSTON: AV. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.7	9.9	3.2	2.3	4.0	6.4	.7	1.2	1.9
SUN WASTE	0	0	0						
HEAT LOSS	-6.2	-6.2	-6.2	1.8	1.8	1.8	1.8	1.8	1.8
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-15.0	-5.8	-12.5	6.8	8.5	10.9	5.2	5.7	6.4

CHART 4.10 – TRIPLE GLASS: WORST CONDITIONS

1 SQ. FT.

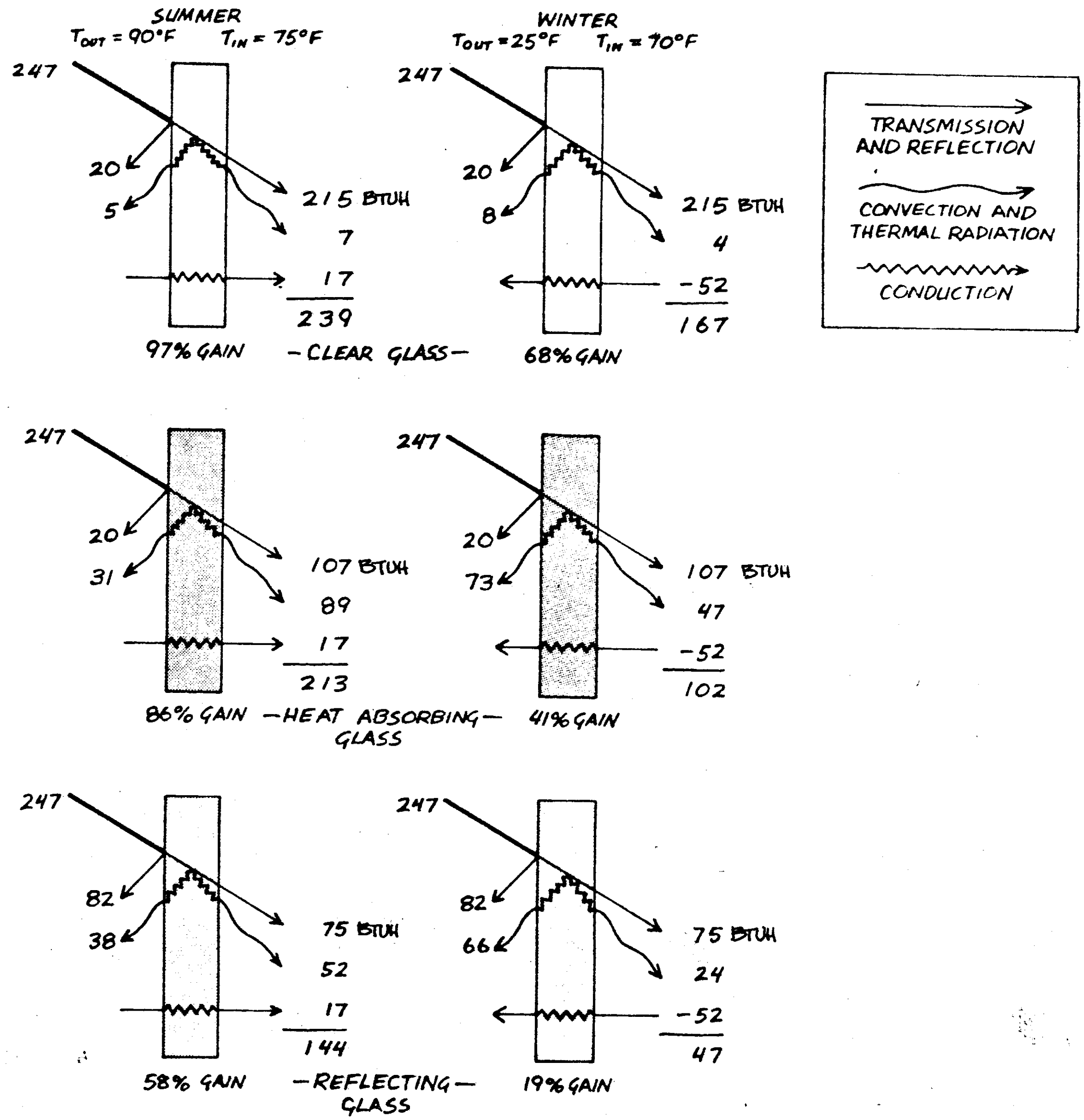
BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.2	3.0	1.0	2.3	4.0	6.4	.7	1.2	1.9
SUN WASTE	0	0	0						
HEAT LOSS	-12.4	-12.4	-12.4	1.8	1.8	1.8	1.8	1.8	1.8
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-31.2	-28.4	-30.4	6.8	8.5	10.9	5.2	5.7	6.4

Because triple glass is generally unavailable in operable windows, 30% double glass will remain the model standard.

Triple glass is $2.50 more expensive than double glass, or .7% more costly per square foot of floor area. The 3% savings for apartment buildings and the 2% savings for office buildings both justify the use of triple glass.

The only drawbacks to its use are unavailability in operable windows and lower transmission of light.

The chart below indicates no preferred orientation for either apartments or offices.



PRICE TAG 4.2

TRIPLE GLASS vs. DOUBLE GLASS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.9	.9	.9	1.5	1.5	1.5
5 YR ENERGY	1.9	2.2	2.7	.4	.4	.5
TOTAL	2.8	3.1	3.6	1.9	1.9	2.0

REFLECTING AND HEAT ABSORBING GLASS

Various types of specially treated glass are available to reduce sungains. The combination of the most effective of these special glasses cannot change the 30% window-to-wall area of the assumed model. A sheet of reflective glass outside of a heat absorbing sheet cannot economically increase the area of west-facing office windows (the most heavily loaded

PERCENTAGE HEAT GAINS THROUGH VARIOUS TYPES AND COMBINATIONS OF GLASS

Glass Type	Summer	Winter
Single Glazing		
Clear	97	68
Heat-absorbing[1]	86	41
Reflective[2]	58	19
Double Glazing		
Clear outside Clear inside	83	68
Clear outside Heat-absorbing inside	74	52
Clear outside Reflective inside	50	42
Heat-absorbing outside Clear inside	42	28
Reflective outside Heat absorbing inside	31	17

[1] Shading coefficient = 0.50
[2] Shading coefficient = 0.35

case).

Specially treated double glass costs at least $2.00 more per square foot of wall area or about .6% more per square foot of floor area.

After subtracting the .6% first cost increase, significant economies can be achieved on the east and west walls of an office building.

PRICE TAG 4.3

REFLECTIVE & HEAT ABSORBING GLASS COMBINATION VS. DOUBLE GLASS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.9	.8	1.5	1.4	1.6	2.9
5YR ENERGY	.9	-4.1	-.1	.4	-.2	.6
TOTAL	1.8	-3.3	1.4	1.8	.4	3.5

REFLECTIVE GLASS OUTSIDE
HEAT ABSORBING INSIDE

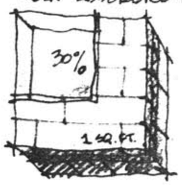


CHART 4.11

BOSTON: AVE. CLIMATE RELATED LOADS

	WINTER			SUMMER UNSHADED		
	N	S	EW	N	S	EW
AVE SUN GAINS	.1	1.9	.6	.8	1.3	2.1
SUN WASTE	0	0	0			
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7
TOTAL	-17.7	-15.9	-17.2	5.9	6.4	7.2

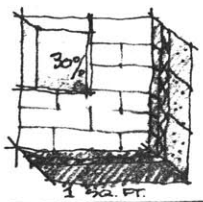


CHART 4.11B

BOSTON: WORST CONDITIONS LOADS

	WINTER			SUMMER UNSHADED		
	N	S	EW	N	S	EW
AVE. SUN GAINS	0	.6	.2	.8	1.3	2.1
SUN WASTE	0	0	0			
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4
INFILTRATION	-19	-19	-19	2.7	2.7	2.7
TOTAL	35.6	35	35.4	5.9	6.4	7.2

MORE DIFFICULT ALTERATIONS

More difficult than merely changing glass types or adding layers are those alterations which necessitate the construction of sun-screening devices or thermal window covers.

SHADES

Although offering significant savings, the sun-shading of windows does not increase optimal window area.

Shading devices can be free when adjacent buildings, trees, or balconies are available, but they can also cost as much as $4 per square foot. If shades are not free, the per cent increase of a building's first cost must be subtracted from any operating savings calculated.

The physical dimensions of various sun-shades can be calculated from sun angle charts, where latitude and time of day and year determine sunshade dimensions. Boston, for instance, should have 1 foot overhangs above south-facing 4 foot windows and 3 feet overhangs above windows facing southeast and southwest.

Window shading devices are recommended for all buildings in the Boston area.

PRICE TAG 4.

SUN SHADED DOUBLE GLASS VS. DOUBLE GLASS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.9	1.3	1.6	1.4	2.1	2.9
5YR ENERGY	1.3	1.8	2.2	.5	.8	1.1
TOTAL	2.2	3.1	3.8	1.9	2.9	4.0

COVERS

Insulated window covers are thermal barriers which are placed over windows during the heating season. These interior 'shutters' may be closed at night or fixed over windows for the entire heating season.

Assuming insulated covers cost $2 per square foot, a building's first cost increases .7% with their use. If covers close either all windows for 1/2 days or 1/2 the windows for the entire season, the reductions in the chart below apply.

Window covers are recommended for apartment buildings in the Boston area because their savings average 3% of original building costs.

Covers do not allow an increase of model window area for any orientation except south. South facing apartments with insulated window covers may have 40% glass walls.

PRICE TAG 4.5

INSULATED COVERS	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	.8	.8	.8	.5	.5	.5
5^{YR} ENERGY	.8	2.1	1.0	.3	.5	.3
TOTAL	1.6	2.9	1.8	.8	1.0	.8

MODEL SURVIVAL

The model has survived the various tests of alternative glass types and the construction of covers and shades. The 30% double glass exterior wall is the most economical possibility

WINDOW COVERS

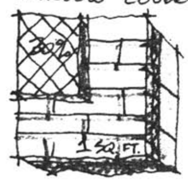


CHART 4.12 BOSTON: AVE. CLIMATE RELATED LOADS

	WINTER					
	N	S	EW			
AVE. SUN GAINS	.8	11.0	3.6			
SUN WASTE	0	0	0			
HEAT LOSS	-5.6	-5.6	-5.6			
INFILTRATION	-9.5	-9.5	-9.5			
TOTAL	-14.3	-4.1	-11.5			

WINDOW COVERS

CHART 4.13 WORST CONDITIONS LOAD

	WINTER					
	N	S	EW			
AVE SUN GAINS	.2	3.3	1.1			
SUN WASTE	0	0	0			
HEAT LOSS	-11.2	-11.2	-11.2			
INFILTRATION	-19.0	-19.0	-19.0			
TOTAL	-30.0	-26.9	-29.1			

within a five year framework. It is now necessary to understand the penalty for stepping outside this model.

+10%

Adding 10% of window area to a Boston building wall results in the following cost increases.

PRICE TAG 4.6

10% ADDITIONAL WINDOW AREA (40% OF WALL)	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	-1.5	-1.6	-1.9	-1.9	-2.3	-2.7
5 YR ENERGY	-2.5	.3	-2.5	-.4	-.3	-.8
TOTAL	-4.0	-1.3	-4.4	-2.3	-2.6	-3.5

CHART 4.14 - ADDING 10% WINDOW AREA: AV. LOADS.

BOSTON: AV. CLIMATE RELATED LOADS 1 SQ. FT. [40% GLASS AREA]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	1.0	14.7	4.8	3.3	5.9	9.5	.9	1.8	3.1
SUN WASTE	0	0	0						
HEAT LOSS	-11.1	-11.1	-11.1	2.9	2.9	2.9	2.9	2.9	2.9
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-19.6	-5.9	-15.8	8.9	11.5	15.1	6.5	7.4	8.7

CHART 4.15 - ADDING 10% WINDOW AREA: WORST LOADS

BOSTON: AV. CLIMATE RELATED LOADS. 1 SQ. FT. [40% GLASS AREA]	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS BTU/H	.3	4.4	1.4	3.3	5.9	9.5	.9	1.8	3.1
SUN WASTE	0	0	0						
HEAT LOSS	-22.2	-22.2	-22.2	2.9	2.9	2.9	2.9	2.9	2.9
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-40.9	-36.8	-39.8	8.9	11.5	15.1	6.5	7.4	8.7

-10%

A 20% glass wall is below a human standard set earlier in this report. It is only mentioned here to point out that 10% glass wall transferred from a north wall to a south wall saves 2% of building costs.

PRICE TAG 4.7

10% LESS WINDOW AREA (20% OF WALL)	% COST REDUCTION: APARTMENT N	APARTMENT S	APARTMENT E/W	OFFICE N	OFFICE S	OFFICE E/W
1ST COST	1.2	1.3	1.6	1.7	1.9	2.5
5 YR ENERGY	1.9	-.6	1.9	.6	.3	.7
TOTAL	3.1	.7	3.5	2.3	2.2	3.2

CHART 4.16 - REDUCING WINDOW AREA 10% : AV. CONDITIONS

BOSTON: AV. CLIMATE RELATED LOADS [20% GLASS AREA]	WINTER N	WINTER S	WINTER E/W	SUMMER UNSHADED N	SUMMER UNSHADED S	SUMMER UNSHADED E/W	SUMMER SHADED N	SUMMER SHADED S	SUMMER SHADED E/W
AV. SUN GAINS BTU/H	.5	8	2.4	1.9	3.1	4.6	.6	.9	1.4
SUN WASTE	0	0	0						
HEAT LOSS	-6.4	-6.4	-6.4	1.8	1.8	1.8	1.8	1.8	1.8
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	7.7	7.7	7.7
TOTAL	-15.4	-7.9	-13.5	6.4	7.6	9.1	6.3	5.4	5.9

CHART 4.17 - REDUCING WINDOW AREA 10% : WORST CONDITIONS

BOSTON: AV. CLIMATE RELATED LOADS [20% GLASS AREA]	WINTER N	WINTER S	WINTER E/W	SUMMER UNSHADED N	SUMMER UNSHADED S	SUMMER UNSHADED E/W	SUMMER SHADED N	SUMMER SHADED S	SUMMER SHADED E/W
AV. SUN GAINS BTU/H	.2	2.2	.8	1.9	3.1	4.6	.6	.9	1.4
SUN WASTE	0	0	0						
HEAT LOSS	-12.8	-12.8	-12.8	1.8	1.8	1.8	1.8	1.8	1.8
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-31.6	-29.6	-31.0	6.4	7.6	9.1	6.3	5.4	5.9

1 LAYER GLASS VS DOUBLE GLASS	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	-2.4	-2.4	-2.4	-2.9	-2.9	-2.9
5YR ENERGY	-4.7	-7.3	-4.4	-.9	-1.2	-1.0
TOTAL	-7.1	-9.7	-6.8	-3.8	-4.1	-4.3

TRIPLE GLASS VS. DOUBLE GLASS	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.9	.9	.9	1.5	1.5	1.5
5YR ENERGY	1.9	2.2	2.7	.4	.4	.5
TOTAL	2.8	3.1	3.6	1.9	1.9	2.0

REFLECTIVE & HEAT ABSORB-ING VS DOUBLE GLASS	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.9	.8	1.5	1.4	1.6	2.9
5YR ENERGY	.9	-4.1	-.1	.4	-1.2	.6
TOTAL	1.8	-3.3	1.4	1.8	.4	3.5

SUN SHADED DOUBLE GLASS VS. DOUBLE GLASS	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.9	1.3	1.6	1.4	2.1	2.9
5YR ENERGY	1.3	1.8	2.2	.5	.8	1.1
TOTAL	2.2	3.1	3.8	1.9	2.9	4.0

INSULATED LOUVERS	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.8	.8	.8	.5	.5	.5
5YR ENERGY	.8	2.1	1.0	.3	.5	.3
TOTAL	1.6	2.9	1.8	.8	1.0	.8

10% ADDITIONAL WINDOW AREA	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	-1.5	-1.6	-1.9	-1.9	-2.3	-2.7
5YR ENERGY	-2.5	.3	-2.5	-.4	-.3	-.8
TOTAL	-4.0	-1.3	-4.4	-2.3	-2.6	-3.5

10% LESS WINDOW AREA	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	1.2	1.3	1.6	1.7	1.9	2.5
5YR ENERGY	1.9	-.6	1.9	.6	.3	.7
TOTAL	3.1	.7	3.5	2.3	2.2	3.2

	N	S	E/W	N	S	E/W

LIGHTING COSTS

Lighting has had no place in the discussion of window sizes because the savings produced by the introduction of additional natural light are insignificant beside heating and air conditioning losses.

APARTMENT LIGHTING

Daytime lighting bills account for only .2% of an apartment's five year total costs. The percentage of this amount which may be eliminated by the use of natural lighting has no effect on overall building economy.

OFFICE LIGHTING

Unless evening work is prohibited, no reduction in office lighting installation is possible. Five years of energy reduction is the only savings which is produced by the use of more daylighting in offices. A scale model shows that if window walls are increased in area from 30% to to 40% of a wall, a 10% reduction in daytime lighting costs is possible. That 10% represents a .4% reduction in total 5 year costs. Heating and air conditioning penalties for increasing glass areas greatly exceed this lighting advantage. The calculations for the most economical window size, therefore, do not include natural lighting considerations.

ECONOMIC GUIDELINES

The following is made up of the 'window conclusions' drawn from discussions of this chapter. These conclusions determine:

*the most economical size and type of window

*the penalties for departing from that size and type

*the special devices which may be exploited in particular situations. (Special devices may be quickly read and compared in chart 4.18 on the following page.)

GUIDELINES

1) Use double glass in 30% window walls.
2) Use summer sun shades.
3) Use triple glass on fixed windows.
4) Use winter window covers.
5) Use reflective and heat absorbing glass on the

north and E/W windows of offices.

6) Trade N and E/W glass for south glass in apartments.

PERSONAL GUIDELINES

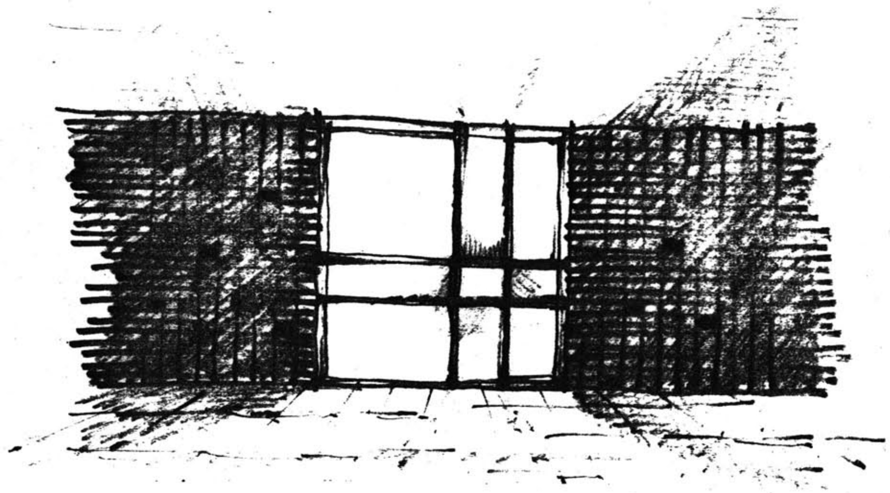
The guidelines developed in this section are subjective and personal. Lest important aesthetic concerns become completely subjected to energy objectives, aesthetic values related to the subject matter of this chapter will be listed and discussed.

If the reader finds this type of discussion useless s(he) is encouraged to proceed to the next mechanical section.

NATURAL LIGHT PHILOSOPHY

Window Area & Orientation

Although I'm not prepared to assign exact lighting levels to different room types, I can



suggest a few guidelines:

*Every living unit and working unit should be provided with a full range of natural lighting experiences. Some spaces should be dim and cavelike and some should be brilliantly lit. This variety should be limited by the following situations.

*No function should be completely glared or glared out. Glare occurs when one-third of a person's 30° cone of vision is 10 times brighter than the other two-thirds. Glare, despite its nasty connotations can be a beautiful sensation. Often, however, it brings only distraction and discomfort.

*A grayed-out space is very dim, having a uniform lighting level below 30 foot-candles, or below reading level.

*One of an architect's formal concerns should be to develop a range of beautiful lighting compositions for different units and groups of units.

Window Covers

Covers are used to improve the thermal resistance of a window. The use of covers, however, eliminates both natural lighting and outside contact.

Evening window covers are effective without eliminating natural light. Some views are eliminated but the resulting interior privacy is often desirable.

Seasonal covers, on the other hand, take large areas of window out of a room for an entire winter or summer.

*If seasonal covers are to be used, they should not cover all windows, and probably none completely. Perhaps fewer very bright situations should be provided in winter, but some should remain.

APPEARANCE

The use of glass in buildings offers architects 3 special aesthetic devices:

1) Windows may be designed as voids cut into solid walls.

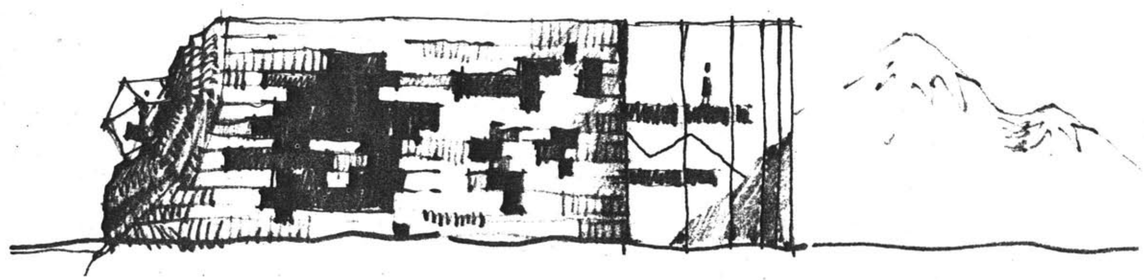
2) The transparency of glass can be contrasted with the opaqueness of solid walls.

3) The husk-like roughness of opaque building materials can be used as the setting for glass jewels.

*The architect should consciously manipulate these devices when composing a building.

Window Covers and Screens

Window covers and screens



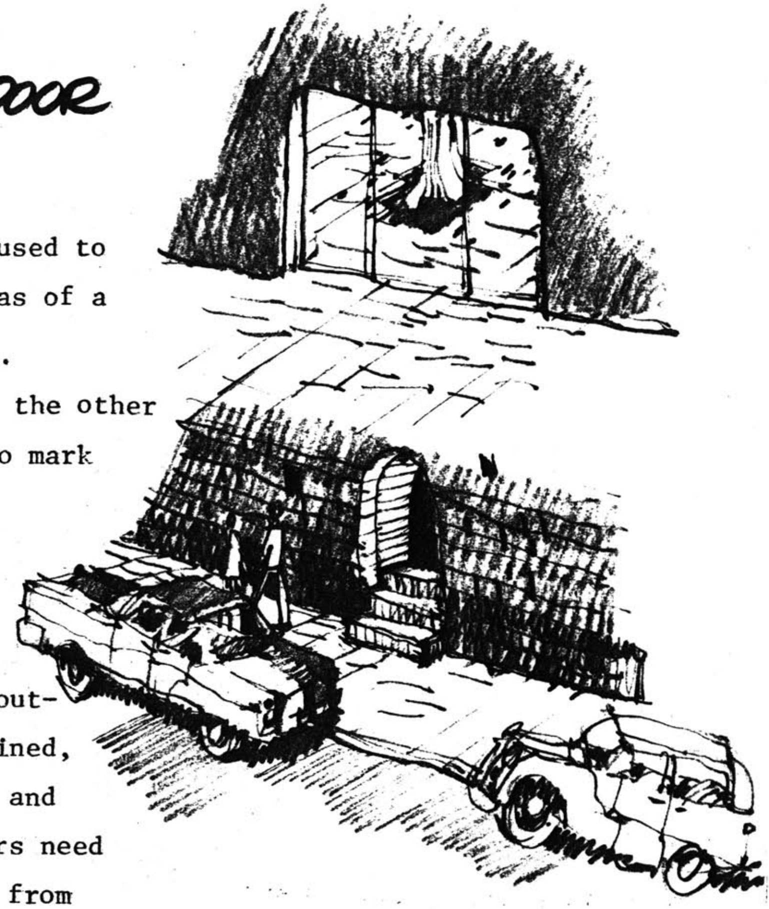
give an architect more things to design. That's wonderful, especially if these things can pay for themselves.

*The architect's task is to deal with window covers and screens as part of his overall design, rather than applying them afterwards as a 'technical expedience.'

Special Effects

*One special lighting effect should be built into every living and working unit. One specially formed opening and spark of colored light should find its way into each unit.

INDOOR - OUTDOOR CONNECTION



Glass should be used to bring the outside areas of a home or office inside.

Opaque walls, on the other hand, are best used to mark boundaries and secure privacy.

Window Covers

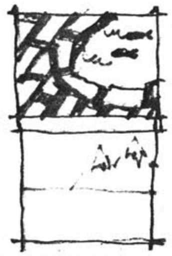
As long as some outside views are maintained, daily shading devices and nighttime window covers need not seriously detract from the quality of interior space.

*Seasonal covers, however, must not completely cut important indoor/outdoor connections for long periods of time.

Views

*A full range of views is most desirable. That is:

1) Some long views
2) Some short views
3) Some multi-directional views.



This range gives an occupant a sense of place within his immediate and general neighborhood.

A full range of views must be provided for each living and working unit.

PERSONAL GUIDELINES

The following are my personal priorities concerning the use of windows.

1) Create a full range of lighting experiences within each living or working unit.

2) Create a variety of lighting experiences throughout a building.

3) Explore the special artistic opportunities provided by windows: solid-void, transparent-opaque, husk-jewel.

4) Bring outside in where desirable.

5) Create a full range of views for each living or working unit: short, long, multidirectional.

6) Design covers and screens.

7) Provide one special effect per unit.

HARD AND SOFT OBJECTIVES

Hard Objective

The following chart orders the cost savings of energy consumption and mechanical installation. The final column of the chart combines operating costs to illustrate the total advantage objectives listed.

WINDOWS

CHART 4.18 - HARD GUIDELINES

OBJECTIVES	APARTMENT 5 year energy savings	APARTMENT first cost savings	APARTMENT adjusted first cost savings	OFFICE 5 year energy savings	OFFICE first cost savings	OFFICE adjusted first cost savings*
USE DOUBLE VS SINGLE GLASS	2.4	5.2	7.6	1.0	3.1	4.1
PROVIDE SUNSHADES	1.9	1.4	3.3	.9	2.3	3.2
REDUCE WINDOW AREA 10% [FROM 30%]	1.3	1.4	2.7	.6	2.2	2.8
USE TRIPLE VS. DOUBLE GLASS	2.4	.9	3.3	.5	1.5	2.0
USE INTERIOR INSULATED SHUTTERS (2#/¢ SHUTTERS)	1.2	.1	1.3	.4	-.2	.2
USE REFLECTIVE GLASS [SOUTH EXCLUDED]	.2	1.0	1.2	.1	2.2	2.3
DO NOT ADD 10% GLASS AREA TO 30%	-1.8	-.9	2.7	-.6	-2.4	-3.0

*Technique for including operation in first cost.
See Chapter I for explanation.

COMBINED OBJECTIVES

The following is my personal stand on where the soft objectives fit into the hard objectives of window efficiency.

1) Create a full range of lighting experiences within each living or working unit.

2) Use proper amounts and types of glass.

3) Create a variety of lighting experiences at the building scale.

4) Designate proper window covers and screens.

5) Exploit the special aesthetic devices provided by window glass: solid-void, transparent-opaque, husk-jewel.

6) Trade N and E/W glass for South Glass in apartments.

7) Bring outside in where desired.

8) Provide range of views: long, short, multi-directional.

9) Provide one special effect per unit.

5 MATERIALS

MATERIALS

V MATERIALS

This chapter develops guidelines for the use of building materials in the construction of beautiful buildings which maintain economical thermal comfort.

Some desired thermal effects will work hand-in-hand with desired architectural effects. Some will work at cross-purposes and will require a compromise solution. This chapter will conclude with guidelines for greatest economies of mechanical costs combined with the author's aesthetic guidelines.

MECHANICAL COST ISSUES

The following issues have an important impact on the mechanical costs of the proposed model building:

1) Insulation -- As much heat and cold resistance must be built into exterior walls as a building's budget will reasonably allow.

2) Mass -- The weight of a building should be used to regulate interior temperatures by either transferring heat loads to more desirable times of day, or by blunting the effects of severe instantaneous changes in outside temperature.

3) Color -- The reflection and absorption of light and heat are properties of color. The efficient absorbtion of sun heat into a building's structure should be investigated for mechanical cost advantages.

The reflection of interior light should be used to decrease electrical lighting loads.

4) Texture -- The reflection and absorption of light and sun heat should be promoted by the choice of proper surface textures.

These four issues will now be separately analyzed for mechanical cost savings.

INSULATION

A wall's insulation is a thermal barrier between outside temperature and internal comfort. Insulation takes on its greatest importance in the winter when average outside temperatures differ from interior comfort by 35°. Insulation in summer is less important because average outside Boston temperatures are only a few degrees above interior comfort.

1 INCH FOAMED GLASS

1977 BUILDING COST FILE - EASTERN EDITION

UCI	DESCRIPTION	UNIT	TOTAL	LABOR	MATERIAL
07200	INSULATION				
07200	INSULATION				
.0406	3/4 INCH URETHANE	SF	0.39	0.21	0.18
.0410	1 INCH URETHANE	SF	0.47	0.21	0.26
.0414	1-1/2 INCH URETHANE	SF	0.63	0.24	0.39
.0420	2 INCH URETHANE	SF	0.76	0.24	0.52
.0510	1 INCH FOAMED GLASS	SF	0.45	0.21	0.24
.0514	1-1/2 INCH FOAMED GLASS	SF	0.57	0.21	0.36
.0520	2 INCH FOAMED GLASS	SF	0.72	0.24	0.48
.0610	1 INCH WOOD FIBRE BOARDS	SF	0.32	0.21	0.11
.0620	2 INCH WOOD FIBRE BOARDS	SF	0.40	0.24	0.16
.0706	3/4 INCH PARTICLE BOARD, COMPRESSED	SF	0.33	0.21	0.12
.0710	1 INCH PARTICLE BOARD, COMPRESSED	SF	0.37	0.21	0.16
.0720	2 INCH PARTICLE BOARD, COMPRESSED	SF	0.56	0.25	0.31
.8101	FOR INTEGRATED VAPOR BARRIER ADD/SF TO MATL COSTS	SF	0.05	----	0.05
.8102	FOR INTEGRAL FOIL BACKING ADD/SF TO MATL COSTS	SF	0.08	----	0.08
.8200	FOR FACTORY PAINTED FINISH ONE SIDE ADD/SF TO MATL COSTS	SF	0.11	----	0.11
.8303	FOR TAPERED TYPE INSULATION, TOTAL AVERAGE OF THREE INCHES THICK ADD 65 PCT TO TOTAL COSTS	PCT			
.8304	FOR TAPERED TYPE INSULATION, TOTAL AVERAGE OF FOUR INCHES THICK ADD 90 PCT TO TOTAL COSTS	PCT			
07215	SPRAYED ON INSULATION				
.0100	POLYSTYRENE FOAM	SF	0.64	0.46	0.18
.0200	URETHANE FOAM	SF	0.71	0.45	0.26

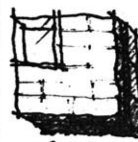
Rigid insulation must be used in the model situation because it is waterproof and may be used in the cavity of a masonry wall where moisture will collect. The type of rigid insulation used is 'foamed glass.' It is a good choice because of its high thermal resistance and low cost.

One inch of foamed glass costs less than two inches, and two inches less than three. The following calculations will be made to compare the total 5 year costs of each of these 3 thicknesses. Figure 5-1 is the wall chart for the model which uses 2 inches of foamed glass insulation. Figure 5-2 is the wall chart of an identical wall except for the use of only 1 inch of insulation.

The winter heating loads through these 2 walls are translated into mechanical and energy costs and compared in the price tag below. The initial savings to a building's budget produced by using 1 inch of insulation rather than 2 inches is very slight (o.15%) and cannot off-set the mechanical cost advantages of 2 inch insulation.

CHART 5.1 MODEL WALL CHART

BOSTON: AV. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2



BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-35.4	-32.3	-34.5	7.7	9.5	12.2	5.9	6.4	7.2

PRICE TAG 5.1

2 INCHES INSULATION VS. 1 INCH	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1st COST	.3	.4	.3			
5YR ENERGY	.4	1.1	.5			
TOTAL	.7	1.5	.8			

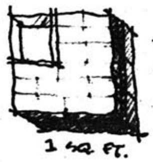
3 INCHES FOAMED GLASS

Chart 5-2 also shows the thermal load on the model masonry wall when 3 inches of foamed glass is placed in the slot between brick and block.

The 'price tag' below shows the cost reductions produced by reduced mechanical equipment and energy consumption. The additional cost of the extra inch of insulation is $.10 per square foot of wall or about .3% of total con-

CHART 5.2

1 INCH FOAMED GLASS (1 SQ. FT.)	WINTER (AV. LOADS)						WINTER (WORST CONDITIONS)		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS									
"									
HEAT LOSS 2"/1"	-8.3/-9.4	-8.3/-9.4	-8.3/-9.4				-16.6/-18.8	-16.6/-18.8	-16.6/-18.8
"									
LOAD ADVANTAGE 2"/1"	6%	16%	8%				6%	7%	6%



3 INCHES FOAMED GLASS (1 SQ. FT.)	WINTER (AV. LOADS)						WINTER (WORST CONDITIONS)		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS									
"									
HEAT LOSS 3"/2"	-7.9/-8.3	-7.9/-8.3	-7.9/-8.3				-15.8/-16.6	-15.8/-16.6	-15.8/-16.6
"									
LOAD ADVANTAGE 3"/2"	2%	6%	3%				2%	2%	2%

struction. But mechanical savings are so low that the small cost of a third inch of insulation cannot be justified within five years.

PRICE TAG 5.2

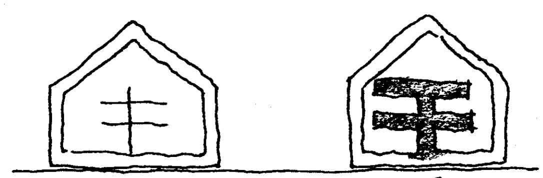
3 INCHES INSULATION VS. 2 INCHES	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	.1	.1	.1			
5^{YR} ENERGY	.14	.4	.2			
TOTAL	.24	.5	.3			

INSULATION CONCLUSION

The original model assumption using 2 inches of foamed glass insulation is economically justified for a project that must pay for itself within a five year period. If any less expensive, rigid insulation with a greater thermal resistance becomes available, than its use would be recommended. At present, two inches of foamed glass would make the best investment.

MASS

Mass creates thermal inertia or the reluctance of a building's interior temperature to change quickly. The mass of a building should be as closely coordinated with heating and cooling loads as initial construction costs and soil conditions will permit. Thermal inertia may be understood by the following example:



1. 2.

In winter, buildings 1 and 2 both have interior temperatures of 70°F. All the molecules inside each building are 70°F, but building 2 has a much heavier internal structure and thus many more 70° molecules. If both of these buildings are identically insulated they will lose exactly the same amount of heat per hour through their weatherskins.

If the furnaces in both buildings are shut down, the temperature ture of building 1 will drop more quickly because each BTU of heat lost to the outside represents a larger proportion of its total stored heat. The greater number of of 70° molucules in building 2 add up to a larger amount of stored heat and give building number 2 a larger thermal inertia. It is true that both buildings will eventually lose all of their heat, but the time lag provided by the massive building creates opportunities for savings of both energy and mechanical equipment.

Boston's climate offers 3 opportunities for reducing mechanical and energy costs using massive construction.

Two of these opportunities include a massive building's ability to shift outside climate induced loads to different times of the day when they are more easily handled. The third opportunity involves another time displacement of loads, but these loads are internally produced by people, lights, and machines.

MASS AND EXTERIOR CLIMATE

Adobe houses in Arizona have nothing to do with Boston. I point this out because everyone has seen amazing diagrams that show walls produced by humble Indians exactly proportioned to permit daytime sunheat to arrive at their interior surface in the cool of the night.

The difference between Boston and Arizona is that Boston has cold winters and unreliable sunshine. Because the walls of Boston's buildings need a large amount of insulation, a properly designed wall could never conduct an exterior sunload through itself in a period of 12 hours. (Besides, who wants midnight temperatures at noon in February?) Timing the heat flow through a properly designed exterior wall in Boston is meaningless.

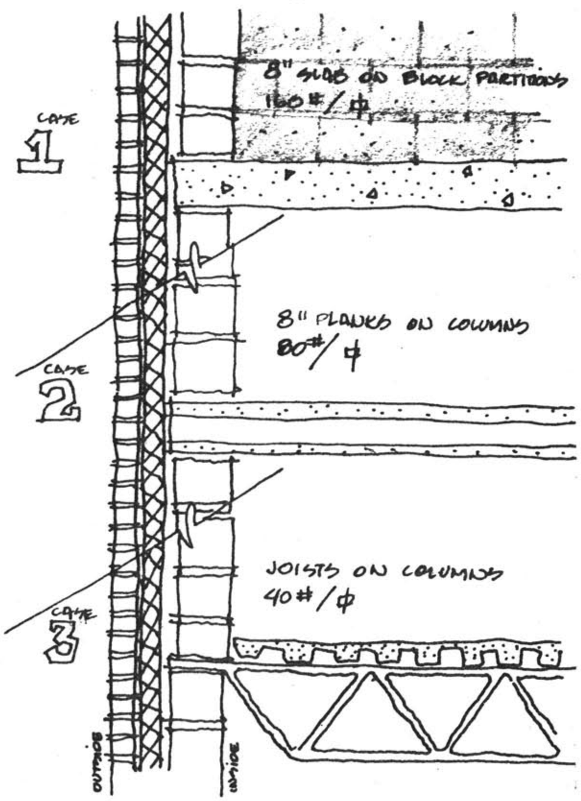
The mass issues which relate to a New England climate are:

1) The summer/fall effect
2) Instantaneous loads.

MASS MODELS

In order to investigate the effects of mass on building mechanical costs, the thermal performance of three different construction methods will be analyzed. The weights of these 3 structures vary in a ratio of 1:2:4.

Assuming the constuction costs of these structural systems are comparable, their 5 year costs may be compared on the basis of the cost of their required mechanical equipment and energy consumption. The present market costs of these various structural systems and the penalty for building heavily on poor soil will be discussed later.



MASS AND OUTSIDE TEMPERATURE

The simplest way to understand the relationship of interior mass-stored heat and outside temperature is to imagine that the heat lost through the skin of a building is directly subtracted from the building's store of potential heat. In fact, some of this heat moves out of the structure into the room's air before passing through the weather skin; this complex relationship may be approximated with a high degree of accuracy by considering the heat losses of a building to be 'sucked' directly from the structural mass of that building. The approximation is made possible because the room air temperature stays close to the temperature of the mass. (See Appendix A for calculation.)

SUMMER / FALL EFFECT

Reductions in air conditioning costs are the only significant savings at stake from June through September. Nearly all residential cooling loads occur during this period. Residential heating is occasionally necessary but only a minute proportion of annual heating loads occur at this time and may be disregarded.

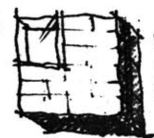
Three pieces of charted information are required in order to make this evaluation. The first is the model wall chart (5-3) showing hourly heat gains through the identical walls of the three structural types. Chart 5-4 illustrates the response of the interior temperatures of the three differently weighted structures. Chart 5-6 is a federal document listing outside temperatures for every 3 hour period for the month of July. (3 hour charts for the other 3 summer/fall months are available in Appendix B.)

The summer/fall advantage of a heavy building is that its slower moving internal temperature is less likely to exceed human comfort before it is unloaded by cooler temperatures that normally occur during the evening hours. On an average summer evening, the introduction of outside air will unload the interior mass-stored heat of all three model structures in less than 6 hours. (See Appen-

CHART 5.3

1 SQ. FT.

BOSTON: AV. CLIMATE RELATED LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.8	11.0	3.6	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-8.3	-8.3	-8.3	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-9.5	-9.5	-9.5	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-17.0	-6.8	-14.2	7.7	9.5	12.2	5.9	6.4	7.2



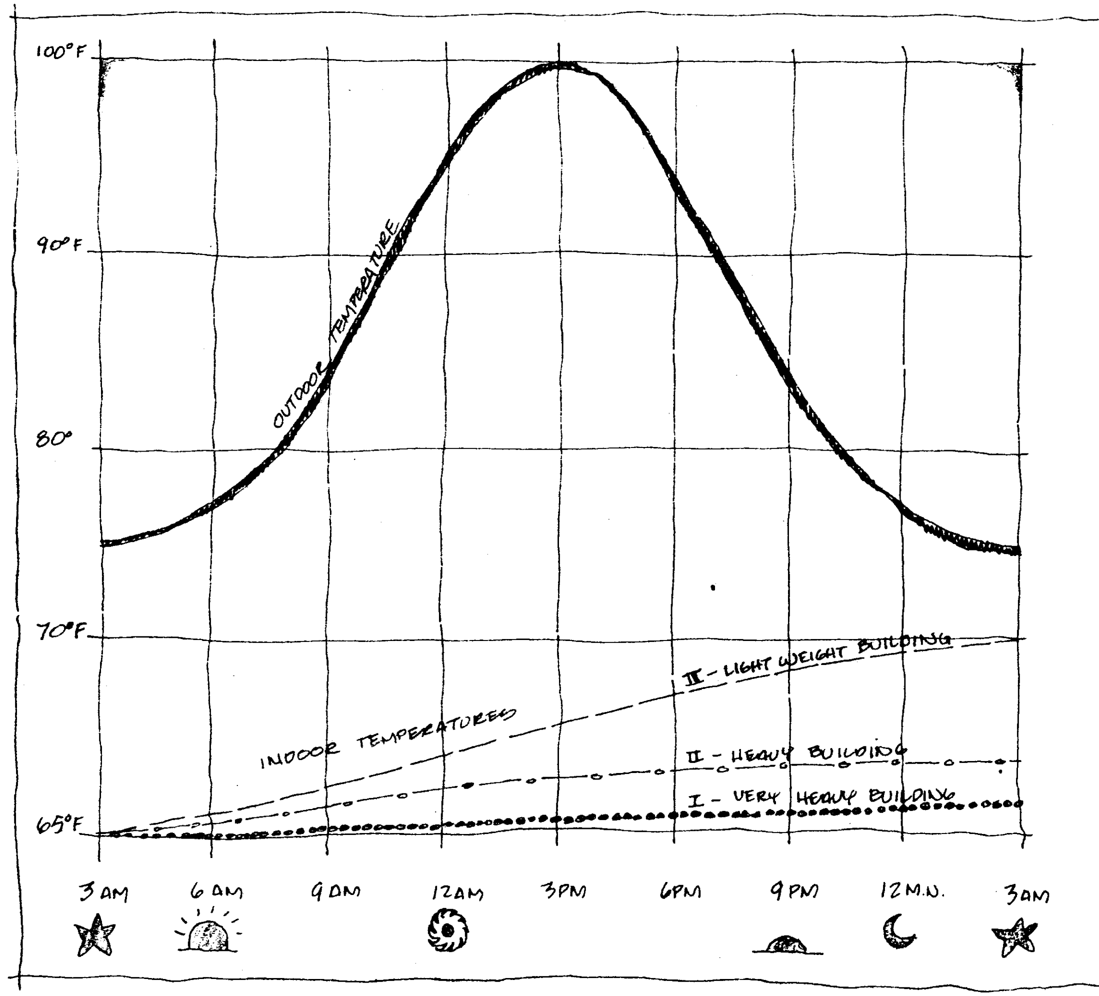
1 SQ. FT.

BOSTON: WORST CONDITIONS LOADS	WINTER			SUMMER UNSHADED			SUMMER SHADED		
	N	S	E/W	N	S	E/W	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1	2.6	4.4	7.1	.8	1.3	2.1
SUN WASTE	0	0	0						
HEAT LOSS	-16.6	-16.6	-16.6	2.4	2.4	2.4	2.4	2.4	2.4
INFILTRATION	-19.0	-19.0	-19.0	2.7	2.7	2.7	2.7	2.7	2.7
TOTAL	-35.4	-32.3	-34.5	7.7	9.5	12.2	5.9	6.4	7.2

dix C for calculation.)

In order to evaluate the effectiveness of mass, the temperature rise through each day of the month must be plotted. Some nights outside temperatures remain high and prevent the structure from unloading its stored heat, and interior temperature must rise through another day. The probability of successive days of unloaded heat gains will determine the probability of each structure's interior temperature exceeding comfort levels. If a severe heat wave forces all 3 structures above comfort levels, the same amount of energy will be necessary to bring each back to 75°F. All energy savings arguments, therefore, must be based strictly on the probability of a

CHART 5.4 - WORST CASE COOLING LOAD FOR I, II, III



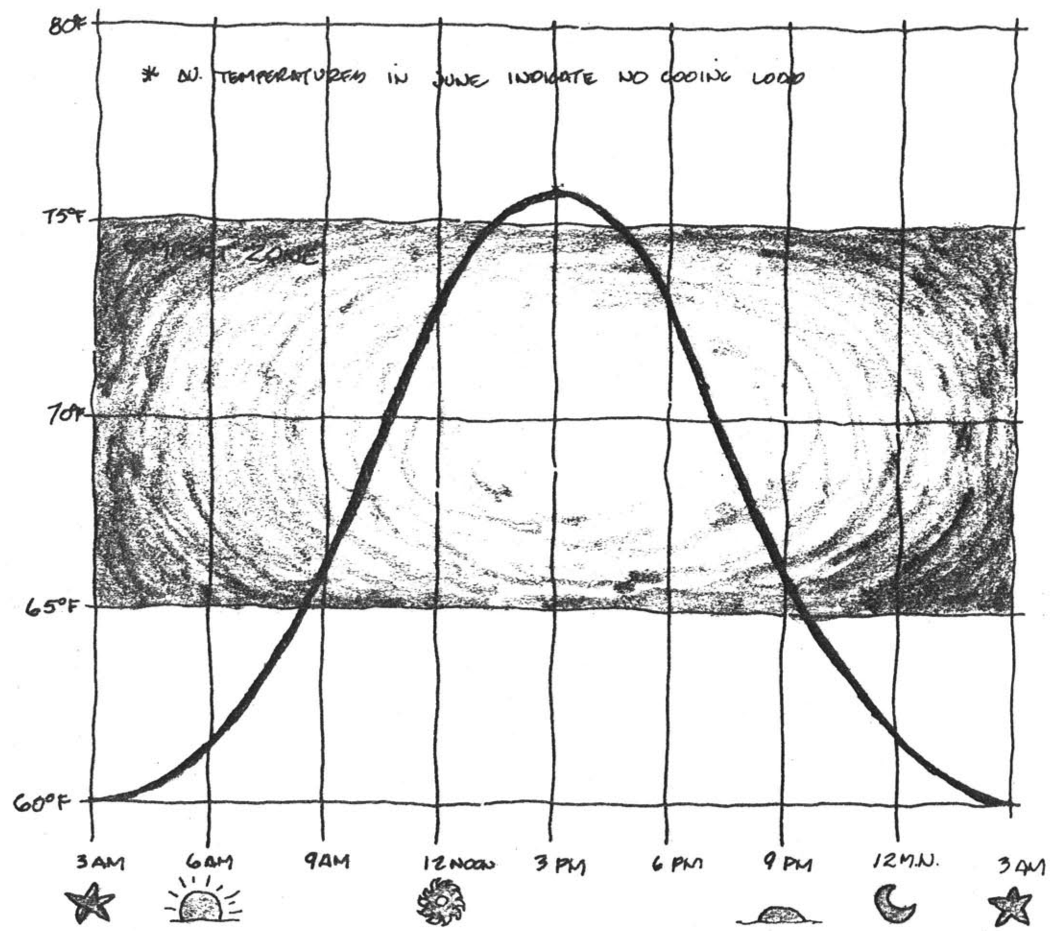
structure's interior temperature exceeding comfort.

Chart 5-4 is the yardstick for measuring structure temperature rises. If daily outdoor temperature curves for a particular day are half as high as the 100° F day curve show, than half of the indoor temperature gains in Chart 5.4 must be added to the structure's temperature.

The 3 hour temperature recordings for the entire summer/fall season have been analyzed and the gains of each structure's interior temperature have been plotted to obtain the number of times each structure will exceed 75°F, the upper limit of comfort.

Chart 5-6 is a sample of the 3 hour temperature chart for the month of July. Those consecutive

CHART 5.5-AV. COOLING LOADS

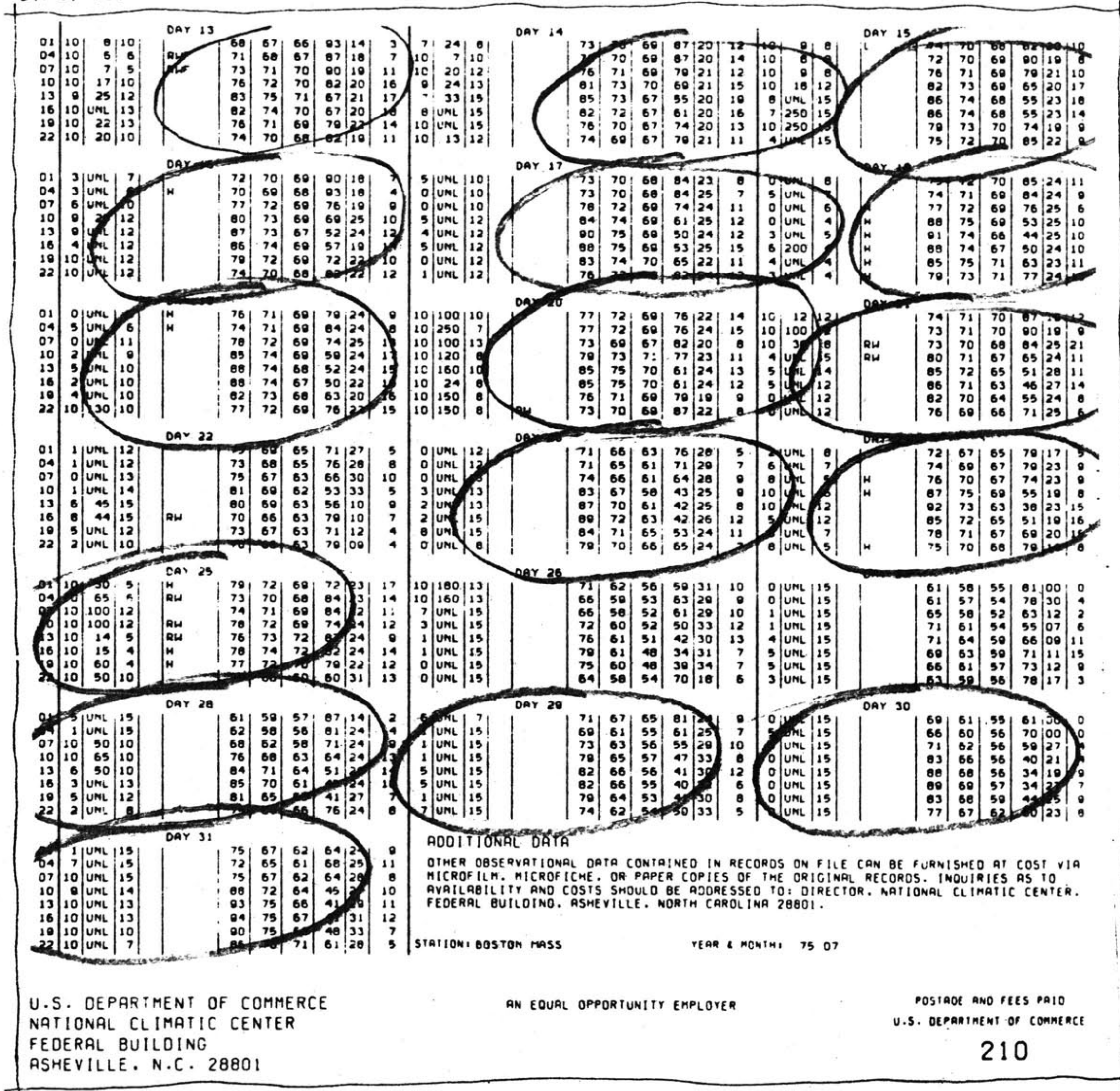


days of high evening temperatures during which structure-stored heat cannot be unloaded have been circled. These are the critical days that force interior temperatures to their maximums. Chart 5-7 on the following page lists the interior temperature gains for each structure during each circled period of consecutive hot days.

The probability of temperatures inside the very heavy structures exceeding comfortable temperatures is low. During the entire summer/fall period of 1976 the very heavy building only made half the journey to the upper limit of thermal comfort.

The heavy building, or plank building during 1976, exceeded the comfort limit once and closely approached it once. Considerable

CHART 5.6 — 3HR. CHART SAMPLE: JULY 13 – 31



mechanical cooling would be required to bring this heavy building back below the line.

Building III, the lightest of the 3 investigated, is assumed to be an average building with average air-conditioning equipment and cooling bills. Because of its lower thermal enertia, it is most often above the comfort line.

Chart 5-7 assumes ideal use of building mass, where occupants understand that windows should be kept shut when outside temperatures are high in order to keep the mass stored cooling from discharging. When using these figures, some allowance must be made for human efficiency. My position is that people will generally use thermal storage correctly because their personal comfort is at stake.

CHART 5.7 MAXIMUM '76 INTERIOR GAINS

PERIOD OF CONSECUTIVE UNLOADED DAYS	STARTING TEMPERATURE	FINAL TEMPERATURE BLDG. I	FINAL TEMPERATURE BLDG. II	FINAL TEMPERATURE BLDG. III
JUNE 23–24	69°F	71°F	72°F	77°F
JULY 11–21	70°F	72°F	76°F	90°F
JULY 23–25	71°F	72.4°F	73.8°F	78°F
JULY 28– AUG. 2	65°F	70°F	74.5°F	90°F
AUGUST 13– 15	70°F	71.2°F	72.4°F	76°F

* ASSUMING SUN-SHADED WINDOWS

During the year analyzed structure II was 60% less likely to exceed internal thermal comfort than structure III. When it did, it required the same energy and equipment to bring it back to desirable temperature. No reduction in cooling equipment is made possible by the weight of structure II, but a 60% energy reduction for air conditioning results from its 60% lower likelihood of reaching temperatures that require cooling.

The price tags below compare the heavy and very heavy structures to the more normal 'light' structure (III). Building I was credited with totally eliminating air conditioning and building II with a 60% reduction in air conditioning energy costs.

PRICE TAG 5.7

SUMMER/FALL EFFECT I VS III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	3.0	3.0	3.0			
5YR ENERGY	3.4	3.4	3.4			
TOTAL	6.4	6.4	6.4			

PRICE TAG 5.7A

SUMMER/FALL EFFECT II VS III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	0	0	0			
5YR ENERGY	2.1	2.1	2.1			
TOTAL	2.1	2.1	2.1			

Offices are not included in the preceding discussion because their higher internal heat component will always demand summer/fall air conditioning. Offices will be discussed later in this chapter when internal office gains are analyzed.

INSTANTANEOUS LOADS

Heating and cooling equipment is adequately sized to protect interior temperature against severe cold snaps in winter and sudden summer heat waves. A massive building won't feel the shock which a light weight building will experience. If the sudden losses or gains are small enough, no extra capacity need be added to the equipment required to handle average loads.

The severe cold snap to be considered is a 10°F drop from 10°F to 0°F in 1 hour. The heat wave will be a 5° rise from 95°F to 100°F in one hour.

Chart 5-8 shows the loads on the model wall section before and after sudden changes, and the temperature movements produced by these 'instantaneous' loads.

The chart shows how little the thermostat in a very massive building will move. A light building's thermostat drops an appreciable 1.5°F during cold snaps

PRICE TAG 5.8

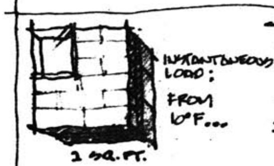
INSTANTANEOUS LOAD COSTS STRUCTURE I VS. STRUCTURE III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST	.8	.9	.8	.8	.9	.8
5YR ENERGY	X	X	X	X	X	X
TOTAL	.8	.9	.8	.8	.9	.8

PRICE TAG 5.8A

" STRUCTURE I VS. STRUCTURE II	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.4	.5	.4	.4	.5	.4
5YR COST	X	X	X	X	X	X
TOTAL	.4	.5	.4	.4	.5	.4

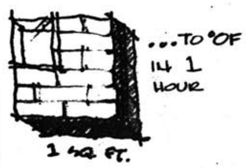
* CONSTRUCTION COSTS NOT INCLUDED

CHART 5.8 – INSTANTANEOUS LOADS: WINTER



INSTANTANEOUS LOAD: FROM 0°F...

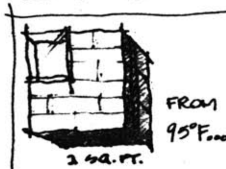
	WINTER		
	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1
SUN WASTE	0	0	0
HEAT LOSS	-14.2	-14.2	-14.2
INFILTRATION	-16.3	-16.3	-16.3
TOTAL	-30.3	-27.2	-29.4



...TO °F IN 1 HOUR

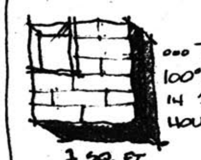
	WINTER		
	N	S	E/W
AV. SUN GAINS	.2	3.3	1.1
SUN WASTE	0	0	0
HEAT LOSS	-16.6	-16.6	-16.6
INFILTRATION	-19.0	-19.0	-19.0
TOTAL	-35.4	-32.3	-34.5
ΔT STRUCTURE I	1.4°F	1.3°F	1.4°F
ΔT STRUCTURE II	0.6°F	0.6°F	0.6°F
ΔT STRUCTURE III	0.3°F	0.3°F	0.3°F

CHART 5.8A – INSTANTANEOUS LOADS: SUMMER



FROM 95°F...

	SUMMER UNSHADED		
	N	S	E/W
AV. SUN GAINS	2.6	4.4	7.1
SUN WASTE	X	X	X
HEAT LOSS	3.2	3.2	3.2
INFILTRATION	3.6	3.6	3.6
TOTAL	9.4	11.4	13.9



...TO 100°F IN 1 HOUR

	SUMMER UNSHADED		
	N	S	E/W
AV. SUN GAINS	2.6	4.4	7.1
SUN WASTE	X	X	X
HEAT LOSS	4.8	4.8	4.8
INFILTRATION	5.4	5.4	5.4
TOTAL	12.8	14.6	17.3

* ALL SUMMER ΔT'S ARE INSIGNIFICANT

and will require immediate correction. The price tag above changes the lighter building for larger equipment needed to cover instantaneous loads, and assumes the heaviest building is totally unaffected by sudden change.

No energy is considered to be saved in this situation because the eventual correction of a .3°F displacement of the heaviest building's interior temperature takes as much energy as the correction of the 1.5°F displacement in the lighter building.

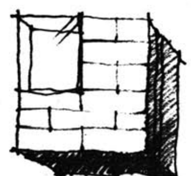
MASS AND INTERIOR CLIMATE

In offices, machines, lights and people produce a great deal of heat. A massive building can absorb a large amount of that heat before its air temperature becomes uncomfortable. The amount of heat

CHART 5.9 - OFFICE LOADS

1 SQ. FT.

AV. HEATING LOAD FOR 8 HR WORK DAY	WINTER		
	N	S	E/W
AV. SUN GAINS (BTU/HR)	2.4	33.0	10.8
HEAT LOSS	-8.3	-8.3	-8.3
INFILTRATION	-19.0	-19.0	-19.0
OFFICE GAINS	37.2	37.2	37.2
WORKING DAY TEMP. GAIN I	0.9°F	2.5°F	1.4°F
WORKING DAY TEMP. GAIN II	1.8°F	5.0°F	2.8°F
WORKING DAY TEMP. GAIN III	4°F	14°F	5.5°F



1 SQ. FT.

AV. HEATING LOAD FOR 16 HR OFF-TIME	WINTER		
	N	S	E/W
AV. SUN GAINS (BTU/HR)	0	0	0
HEAT LOSS	-8.3	-8.3	-8.3
INFILTRATION	-19.0	-19.0	-19.0
OFFICE GAINS	0	0	0
OFF-HOUR TEMP. LOSS I	-4.3°F	-4.3°F	-4.3°F
OFF-HOUR TEMP. LOSS II	-8.6°F	-8.6°F	-8.6°F
OFF-HOUR TEMP. LOSS III	-17.4°F	-17.4°F	-17.4°F

stored in the mass of a heavy building may be either used for evening heating in winter or may be unloaded during summer off-hours by venting interiors with outside air. The amount of heat that a structure can defray to off hours may be counted as an energy savings.

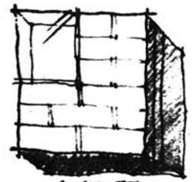
WINTER OFFICE HEAT

Winter mechanical reductions take two forms:

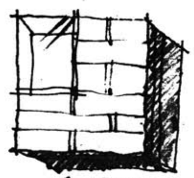
1) The structure in all 3 cases can hold all of the loads available during daytime operation with the exception of those portions of building III which face south. In this case, the lightweight building must throw away enough heat to cover 12% of its 24 hour requirement.

2) Heavy buildings can store so

CHART 5.11 - WORST OFFICE LOADS



WORST HEATING LOAD FOR 8 HR. WORK DAY	WINTER		
	N	S	E / W
AV. SUN GAINS	0.6	9.9	3.3
HEAT LOSS	-16.6	-16.6	-16.6
INFILTRATION	-28.0	-28.0	-28.0
OFFICE GAINS	37.2	37.2	37.2
TOTAL	-7.0	-0.8	-5.2



WORST HEATING LOADS FOR 16 HR OFF-TIME	WINTER		
	N	S	E / W
AV. SUN GAINS	0.0	0.0	0.0
HEAT LOSS	-16.6	-16.6	-16.6
INFILTRATION	-28.0	-28.0	-28.0
OFFICE GAINS	0.0	0.0	0.0
TOTAL	-44.6	-44.6	-44.6
AV. ~~DAILY~~ LOAD (BTU/HR)	11,200	10,500	11,000
CAPACITY REDUCTION I/III	24%	22%	24%
CAPACITY REDUCTION I/II	12%	11%	12%

much daytime heat that their heating systems can be run at a constant rate throughout the 24-hour day, borrowing structure-stored heat at night and building structure-stored heat throughout the work day, but never passing above or below the comfort range.

Light buildings will deplete their structure-stored heat early in the evening if they attempt to borrow from their structure-stored heat at the same rate. Lighter structures need larger mechanical systems to deal with the worst conditions which occur on cold winter nights.

Chart 5-11 shows the loads on worst winter days during work hours and after. The load differences (bottom column) are calculated by dividing 10°F of structure-stored heat by the work hours to determine how much of the evening loads may be defrayed by this free heat. The difference between the free heat and the heat load per hour is the capacity of the heating system each structure would require.

The following price tags compare the cost of the heating systems required by the three different structures.

PRICE TAG 5.9

OFFICE LOADS AND HEATING I vs. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				2	2	2
5YR ENERGY					.5	
TOTAL				2	2.5	2

PRICE TAG 5.9A

OFFICE LOADS AND HEATING I vs. II	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST				1	1	1
5YR ENERGY						
TOTAL				1	1	1

MASS AND OFFICE AIR CONDITIONING

Mass works with summer office cooling loads in 2 ways:

1) For average conditions, a structure may be loaded to its thermal capacity during the day and completely unloaded by venting it with outside air during the evening. This unloading is easily accomplished because the average outside air temperature on summer evenings is 65°F or lower, and the air film surrounding interior mass has a very low thermal resistance. (See Appendix C for calculation.)

2) Some days evening temperatures are too high for a structure to unload its heat. An air conditioning system designed to run at a constant rate throughout the day may

have a smaller capacity in a heavy building because more of the cooling load will be transferred to less critical times of the day. Chart 5.12 lists the different loads on each of the structures after the transfered load has been subtracted.

CHART 5.13-COOLING CAPACITIES

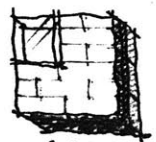
CAPACITY OF COOLING SYSTEMS		
I	4792 BTUH	I/III : -19%
II	5520 BTUH	I/II : -13%
III	5883 BTUH	II/III : -6%

PRICE TAG 5.10 - COOLING LOSS

SUMMER OFFICE COOLING I vs. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				1.5	1.5	1.5
5YR ENERGY				3.0	3.0	3.0
TOTAL				4.5	4.5	4.5

5.13 - OFFICE COOLING CAPACITY

AV. SUMMER OFFICE COOLING 1 SQ. FT. 8HR WORK DAY	SUMMER UNSHADED		
	N	S	E/W
AV. SUN GAINS	5.2	8.8	14.2
HEAT LOSS	2.4	2.4	2.4
INFILTRATION	5.4	5.4	5.4
OFFICE LOAD	37.2	37.2	37.2
TOTAL	50.2	53.8	59.2



1 SQ. FT. 16 HR. OFF TIME	SUMMER UNSHADED		
	N	S	E/W
AV. SUN GAINS	0	0	0
HEAT LOSS	-2.4	-2.4	-2.4
INFILTRATION	-5.4	-5.4	-5.4
TOTAL	-7.8	-7.8	-7.8
ΔT I PER DAY	4°F	4.1°F	4.7°F
ΔT II PER DAY	8°F	8.2°F	9.4°F
ΔT III PER DAY	16°F	16.5°F	19°F

The price tags show the related equipment savings assuming 7 consecutive days during which no unloading can take place.

PRICE TAG 5.10A OFFICE COOLING

SUMMER OFFICE COOLING I VS II	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				.5	.5	.5
5YR ENERGY				.9	.9	.9
TOTAL				1.4	1.4	1.4

CONCLUSION: MASS AND OFFICES

The following are the combined mechanical savings made possible by building massive office buildings. Nearly 3/4 of the total savings are due to air-conditioning reductions.

PRICE TAG 5.11 - OFFICE TOTALS

MASS AND OFFICES I VS. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				3.5	3.5	3.5
5YR ENERGY				3.0	3.5	3.0
TOTAL				6.5	7.0	6.5

PRICE TAG 5.12 - OFFICE TOTALS

MASS AND OFFICES I VS II	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				1.5	1.5	1.5
5YR ENERGY				.9	.9	.9
TOTAL				2.4	2.4	2.4

STRUCTURAL COSTS

The current, in-place costs of the 3 model structures are listed in chart 5-14. The joist building is more expensive than the plank building, but the slab building increases first costs 6% over the plank building. On site form work make it difficult to justify despite its thermal advantages.

A combination of the advantages of I and II is possible by pouring 2 inches of topping over precast planks. If this combination structure is supported by block walls, it will approach the weight of I. The 2 inches of topping will increase first costs by 2%.

CHART 5.14 IN PLACE STRUCTURE COSTS

I	SLAB ON BLOCK 160#/ф	$10.50/ф
II	PLANK ON COLUMNS 80#/ф	$8.00/ф
III	JOISTS ON COLUMNS 40#/ф	$8.75/ф

SOIL CONDITIONS

Foundation costs are proportional to loads on poor soil. If a building's dead load (structure weight) is doubled from II to I, foundation costs increase 70%.

COLOR

The color of material will affect mechanical expenses for the model building only in the case of office lighting. In order to prove this the only viable case, the other properties of color which participate in passive energy flow will be discussed.

roperties **Flexicore**

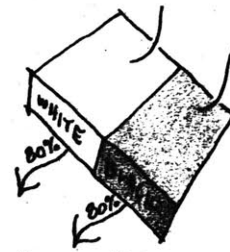
:xicore®

zation: The Flexicore Co. Inc., Dayton, Ohio

2' - 0" x 8" | 2' - 0" x 8" with 2" Topping

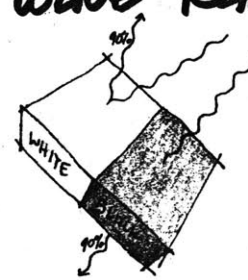
(in.)	I (in.^{4})	Weight (psf)	y_b (in.)	Mom. of Inertia (in.^{4})	Weight (psf)
.00	843	57	5.26	1547	82

COLOR AND LONG WAVE RADIATION



Long wave radiation is heat, not sunshine. It is an infrared wave and is color blind; this form of heat can be absorbed by a white surface as easily as by a black surface. Since all colors absorb the same amount of long wave radiation (90%), color choices are not restricted by ultra red absorbtion or reflection.

COLOR AND SHORT WAVE RADIATION



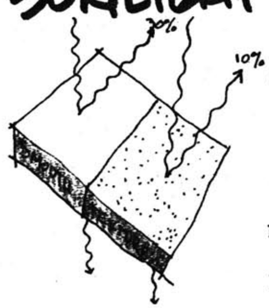
Short vave radiation is sunshine, and is greatedly affected by color choices. White reflects 90% of incident solar radiation while black absorbs 90%.

The model case in this chapter will not be effected by this phenomenon because the windows are small allowing for small amounts of sunshine entry. Little reflection of sunshine back through the windows will take place.

In Boston, the color of a building's exterior walls should have nothing to do with the amount of sunheat it can collect. Sunheat on a wall is only useful if it travels through that wall to its interior surface in a period of 12 hours. This is the principal behind the adobe house where day heat is used to warm the cool evenings. Due to the cold winters, Bostonian walls require large amounts of insulation that create transmission periods many times greater than 12 hours.

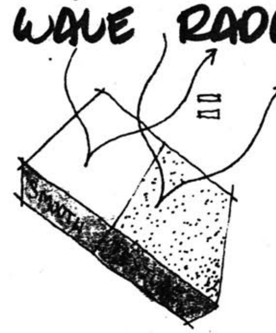
Exterior wall color in Boston is the architects prerogative.

TEXTURE AND SUNLIGHT



Shiny surfaces reflect 30% of incident sunshine. Flat matte finishes reflect approximately 10%. Again, this phenomenon has only a minute affect on the building model because the model's windows are too small to allow significant amounts of sunshine to be reflected back outside.

TEXTURE AND LONG WAVE RADIATION



The absorbency of a surface to infrared radiation is difficult to improve by texturing a surface. Deformation of a surface at the atomic scale can produce some improvement in absorbency, but no texturing at an architectural scale can improve the heat absorption of a surface. The use of textured blocks or textured plaster, for instance, will have no heat absorbing advantages over polished marble.

COLOR AND LIGHT REFLECTION

Reductions both in the number of office lighting fixtures and the amount of office lighting energy requirements are the only important issues that relate color and texture to mechanical costs for our model building.

The lighting requirements of apartments are too low to allow significant cost reductions for the use of lighter interior colors. Conversely, office lighting costs are greatly affected by interior reflectivity.

Black surfaces reflect 10% of the light which falls on them. White reflects 90% of incident light. While no interior is purely black or white, the reflectances of all colors lie between these extremes. 5.14 shows the reflectances of common interior finishes.

The price tag below presents the savings created by an office interior with high surface reflectances (.8) as compared to average reflectances (.5).

PRICE TAG 5.13

OFFICE LIGHT REFLECTION .8 VS. .5	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				3	3	3
5 YR ENERGY				2.6	2.6	2.6
TOTAL				5.6	5.6	5.6

MATERIALS AND THE AUTHOR'S PERSONAL AESTHETIC GUIDELINES

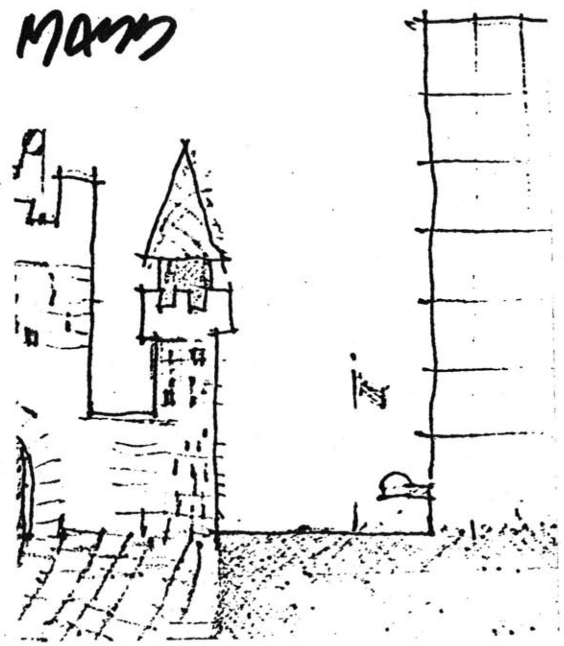
The guidelines developed in this section are subjective and personal. Lest important aesthetic concerns become subjected to energy objectives, aesthetic values related to the subject matter of this chapter will be listed and discussed.

If a reader finds type of discussion useless s(he) is encouraged to proceed to the next mechanical section. The author suggests the reading of these sections. They are brief and offer insights into the test design of the final chapter.

The aesthetic implications of

a building's mass, color, and texture are discussed in terms of their relationship to natural light, their appearance, and indoor/outdoor connecting properties.

Mass



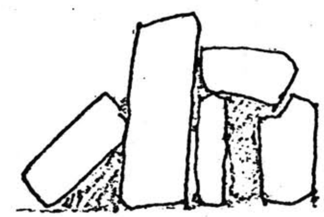
The mass or weight of a building has a large impact on those who see and use that building.

From the outside, heavy buildings are perceived as stable, per-manent, and part of the continuing order of the world. Lightweight, skeletal buildings, on the other hand, are seen as impermanent. The lines of skeletal buildings suggest movement and rarely permit the eye to focus.

Inside, the same feelings are induced from different perceptions. The sound of a voice, the solidity of walls and floor, and the amount of a building's mass seen around or through the windows, tell an occupant that the environment is stable or impermanent.

It is the designer's obligation to specify his intentions concerning a building's place within its community. Is a building to appear permanent, impermanent, in motion, or stable? Any of these themes may be reinforced by the amount of mass presented to a viewer or occupant.

Mass and Appearance

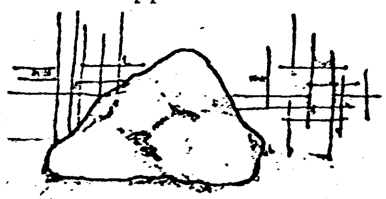


If massive building becomes justified it will return heavy positive elements to an architect's hands. Opaque parts with gravitational rules will join those stream lines elements developed by our preceding generation.

A return to the forms and decorations of Sullivan and Richardson does not seem economically or culturally possible. A new order of heavy building must now be developed with its own full range of parts, from the largest structural elements to the smallest decoration.

MASS AND OUTDOOR CONNECTION

Structures may be massive and have the appearance of being rooted



to the earth or lightweight and floating above their landscape. The heavier masornry parts of a building are most effectively used to continue the out-of-doors inside a building's skin. The lightweight parts of a building are best used to mark boundaries between interior space and the surrounding landscape. The exploitation of these two themes is desirable.

COLOR AND TEXTURE

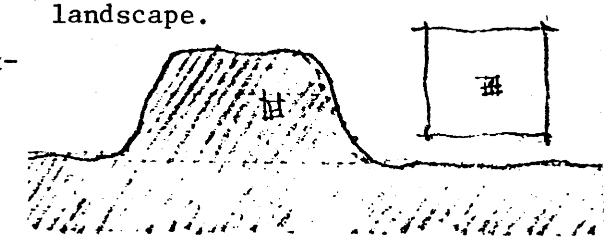
The notion that space can be more effectively studied or appreciated in the absence of color and textures is here rejected. Space is the combination of dimensions with color and texture.

NATURAL LIGHT AND APPEARANCE

The broadest range of lighting effects possible should be presented to an occupant. After a theme for interior light and appearance is developed in accordance with a building's program, the architect must explore all colors, patterns and textures to reinforce that theme. A bright natural light source will either fill a dazzeling white hall or completely dominate a dark space with its beam and vista. These diverse spaces are created solely by an architect's color and texture choices.

INDOOR/OUTDOOR

Colors and textures must be used to create both demarcations and connections of the parts of a building with its surrounding landscape.



COMMUNITY IMPACT

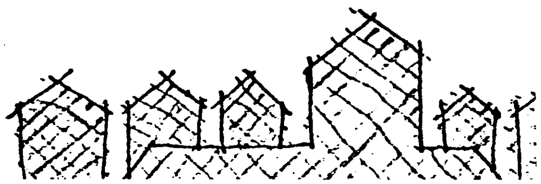
Color and texture must help

CHART 5.15 – HARD GUIDELINES

OBJECTIVES	APARTMENT 5 year energy savings	APARTMENT first cost savings	APARTMENT adjusted first cost savings	OFFICE 5 year energy savings	OFFICE first cost savings	OFFICE adjusted first cost savings*
BUILD HEAVILY 160#/ɸ VS. 40#/ɸ	3.4	3.8	7.2	3.3	3.5	6.8
BUILD HEAVILY 80#/ɸ VS 40#/ɸ	2.1	.4	2.5	.9	1.5	2.4
USE .8 REFLECTANCE VS .5 (IN OFFICES)	—	—	—	2.6	3	5.6

*Technique for including operation in first cost.
See Chapter I for explanation.

state the relative importance of a building to its community and the relationship between the building and its neighborhood.



AESTHETIC CONCLUSIONS

The following is an ordered list of the author's 'soft' guidelines for the use of materials:

1) Reinforce lighting dynamics with rich color choices.
2) Design a complete order of heavy building.
3) Use color, mass, and texture choices to inhance the theme of rooting a building into its landscape or the theme of marking a boundary.

COMBINED GUIDELINES

The following is the ordered list of hard and soft objectives discussed in this chapter.

1) Build as heavily as possible.
2) Reinforce lighting dynamics with the extensive use of color.
3) Design a complete order of heavy construction.
4) Select color, mass and texture for the placement of the proper building within the proper community context.
5) Place dark interior mass in winter sunshine.
6) Design color, mass and texture to exploit themes of 'rooting a building into the landscape' or 'marking territories.'
7) Use white surfaces in offices.
8) Use matte finishes on storage materials.

PRICE TAG 5.2

3 INCHES INSULATION VS. 2 INCHES	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	.1	.1	.1			
5 YR ENERGY	.14	.4	.2			
TOTAL	.24	.5	.3			

PRICE TAG 5.8

INSTANTANEOUS LOAD COSTS STRUCTURE I VS. STRUCTURE III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	.8	.9	.8	.8	.9	.8
5 YR ENERGY						
TOTAL	.8	.9	.8	.8	.9	.8

PRICE TAG 5.10A OFFICE COOLING

SUMMER OFFICE COOLING I VS II	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST				.5	.5	.5
5 YR ENERGY				.9	.9	.9
TOTAL				1.4	1.4	1.4

PRICE TAG 5.7

SUMMER/FALL EFFECT I VS III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	3.0	3.0	3.0			
5 YR ENERGY	3.4	3.4	3.4			
TOTAL	6.4	6.4	6.4			

PRICE TAG 5.9

OFFICE LOADS AND HEATING I VS. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST				2	2	2
5 YR ENERGY					.5	
TOTAL				2	2.5	2

PRICE TAG 5.11 – OFFICE TOTALS

MASS AND OFFICES I VS. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST				3.5	3.5	3.5
5 YR ENERGY				3.0	3.5	3.0
TOTAL				6.5	7.0	6.5

PRICE TAG 5.7A

SUMMER/FALL EFFECT II VS III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST	0	0	0			
5 YR ENERGY	2.1	2.1	2.1			
TOTAL	2.1	2.1	2.1			

PRICE TAG 5.9A

OFFICE LOADS AND HEATING I VS. II	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST				1	1	1
5 YR ENERGY						
TOTAL				1	1	1

PRICE TAG 5.12 – OFFICE TOTALS

MASS AND OFFICES I VS. II	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1^{ST} COST				1.5	1.5	1.5
5 YR ENERGY				.9	.9	.9
TOTAL				2.4	2.4	2.4

PRICE TAG 5.13

OFFICE LIGHT REFLECTION .8 vs. .5	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				3	3	3
5YR ENERGY				2.6	2.6	2.6
TOTAL				5.6	5.6	5.6

PRICE TAG 5.10 — COOLING COSTS

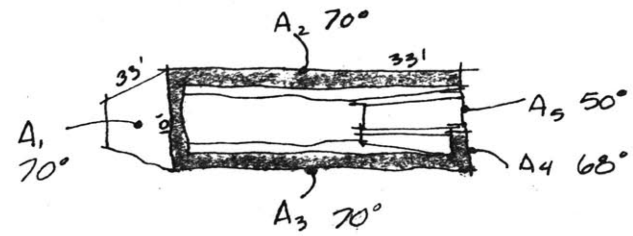
SUMMER OFFICE COOLING I vs. III	% COST REDUCTION					
	APARTMENT			OFFICE		
	N	S	E/W	N	S	E/W
1ST COST				1.5	1.5	1.5
5YR ENERGY				3.0	3.0	3.0
TOTAL				4.5	4.5	4.5

PRICE TAG 5.8A

" STRUCTURE I vs. STRUCTURE II	% COST REDUCTION					
	N	S	E/W	N	S	E/W
1ST COST	.4	.5	.4	.4	.5	.4
5YR COST						
TOTAL	.4	.5	.4	.4	.5	.4

* CONSTRUCTION COSTS NOT INCLUDED

PROOF THAT EXPERIENCED INTERIOR TEMPERATURE STAYS CLOSE TO MASS TEMPERATURE.



$$\text{EXPERIENCED TEMPERATURE (ET)} = \frac{MRT + T_{ROOM\ AIR}}{2}$$

$$MRT = \frac{A_1 \times 70° + A_2 \times 70° + A_3 \times 70° + A_4 \times 68° + A_5 \times 50°}{A_1 + A_2 + A_3 + A_4 + A_5}$$

$$\underline{69.5°} = \frac{1000\phi \times 70° + 1000\phi \times 70° + 1000\phi \times 70° + 300\phi \times 68° + 100\phi \times 50°}{3400\phi}$$

$$\text{ROOM AIR TEMPERATURE } (T_R) = \frac{A_{WEATHER\ SKIN} \times U_{WEATHER\ SKIN} \times T_{AMBIENT} + A_{MASS} \times U_{MASS} \times T_{MASS}}{A_{MASS} \times U_{MASS} + A_{WEATHER\ SKIN} \times U_{WEATHER\ SKIN}}$$

$$T_R = \underline{69°} = \frac{(300 \times .08 + 100 \times .6)(0°) + (3000\phi) \times 1.5 \times (70.3°)}{(3000) \times (1.5) + (300 \times .08) + (100) \times (.6)}$$

$$ET = \underline{69.3°} = \frac{69.5 + 69}{2}$$

∴ EXPERIENCED TEMPERATURE STAYS CLOSE ENOUGH TO MASS TEMPERATURE SO THAT IT NEED NOT BE ANALYZED SEPERATELY.

DAY 10

01	7	UNL	15		73	63	56	55	33	10
04	1	UNL	15		67	59	54	63	31	8
07	0	UNL	15		73	62	55	53	01	8
10	1	UNL	15		75	65	58	56	12	11
13	3	UNL	15		75	64	57	54	07	12
16	2	UNL	15		74	64	58	58	13	13
19	2	UNL	15		71	64	60	68	15	3
22	8	UNL	15		74	65	58	60	23	12

DAY 11

7	250	15		73	65	60	64	25	12
5	UNL	10		67	63	61	81	18	4
2	UNL	7		72	66	63	73	17	6
4	UNL	7		84	70	62	48	19	13
4	UNL	7		86	71	63	46	20	13
6	50	6	H	86	72	65	50	20	10
10	220	5	H	79	72	68	69	22	11
10	100	4	H	75	70	68	73	21	10

DAY 12

10	33	5	TH	72	69	68	87	30	4
10	6	5	F	72	70	69	90	23	7
4	UNL	4	F	75	72	70	85	27	10
5	UNL	10		84	72	66	55	27	15
8	45	12		83	71	65	55	31	8
4	UNL	15		82	69	62	51	31	12
7	200	20		75	66	60	60	32	13
1	UNL	20		71	64	60	68	30	10

DAY 13

01	4	UNL	15		67	63	63	78	29	9
04	[illegible]	120	15		63	60	55	73	32	7
07	10	120	15		65	59	54	68	31	12
10	3	UNL	15		73	62	55	53	29	13
13	10	35	15		75	64	55	52	27	8
16	9	140	15		76	64	57	52	30	10
19	6	250	15		74	64	59	58	30	12
22	3	UNL	15		69	62	58	68	30	10

DAY 14

10	13	15	RW	67	62	58	73	31	6
10	15	15		65	61	59	81	34	4
10	20	15		68	62	60	81	32	7
10	27	15		70	64	60	[illegible]	[illegible]	5
9	30	13		69	66	64	84	35	5
9	41	15	RW	69	66	64	84	27	6
9	60	15		69	65	63	81	34	2
8	65	15		69	62	58	68	33	8

DAY 15

10	33	15		67	62	58	73	34	7
10	46	15		66	[illegible]	58	76	35	7
10	50	15		68	63	58	73	34	9
10	44	15		73	64	[illegible]	62	05	6
10	49	20		70	64	60	71	14	5
5	UNL	15		73	65	60	64	14	7
0	UNL	15		72	66	62	71	15	5
0	UNL	15		70	65	62	76	24	9

DAY 16

01	0	UNL	15		66	64	61	78	24	5
04	0	UNL	10		64	62	60	87	22	4
07	2	UNL	12		73	66	62	69	27	2
10	5	UNL	15		82	69	62	51	18	7
13	8	250	15		80	70	64	58	12	13
16	10	100	15		81	68	61	51	20	16
19	10	90	15		74	66	62	66	20	15
22	10	35	13		71	64	60	68	21	12

DAY 17

10	21	10		70	66	64	81	20	9
10	8	8		71	67	65	81	21	8
10	11	5	F	70	68	67	90	19	4
10	60	6	H	74	71	69	84	20	5
5	UNL	10		84	72	66	55	27	8
4	UNL	10		87	72	65	48	26	12
0	UNL	10		80	66	58	47	29	15
0	UNL	15		71	60	51	49	30	11

DAY 18

0	UNL	15		68	59	52	57	30	13
0	UNL	15		65	57	50	59	30	14
0	UNL	20		69	59	52	55	30	12
0	UNL	25		76	63	54	47	28	15
5	UNL	25		80	63	50	35	27	15
4	UNL	20		81	63	50	34	30	13
1	UNL	20		77	62	52	42	26	13
0	UNL	20		72	61	54	53	25	8

DAY 19

01	0	UNL	20		69	61	55	61	23	9
04	3	UNL	15		71	61	54	55	27	14
07	3	UNL	15		74	63	58	54	27	13
10	1	UNL	15		84	67	57	40	27	15
13	4	UNL	15		88	69	58	38	26	14
16	10	250	15		88	69	58	36	31	12
19	6	UNL	15		85	69	59	41	30	8
22	0	UNL	15		79	69	63	58	27	11

DAY 20

7	200	15		77	67	62	60	29	7
6	180	15		73	67	63	71	25	8
0	UNL	15		76	68	63	60	22	8
3	UNL	15		89	71	62	41	24	15
0	UNL	14		92	70	58	32	25	19
3	UNL	12		90	71	60	37	25	15
10	300	7		82	70	64	55	24	18
10	300	7		76	65	58	54	24	13

DAY 21

10	90	7		75	66	60	60	22	13
10	90	6	RWH	74	66	62	66	24	16
10	80	5	RWH	72	69	67	84	24	13
10	80	5	H	75	71	69	82	24	10
10	60	5	RWH	75	72	71	87	19	9
10	50	4	F	75	72	71	87	22	6
10	24	4	F	71	70	70	97	32	7
10	45	12		71	67	65	81	31	8

DAY 22

01	10	55	13		69	64	61	76	36	8
04	2	UNL	15		65	61	58	78	35	7
07	3	UNL	20		67	59	54	63	02	10
10	0	UNL	20		71	62	55	57	09	12
13	1	UNL	20		71	62	56	59	09	13
16	0	UNL	20		70	63	58	66	12	10
19	0	UNL	20		66	61	57	73	11	9
22	0	UNL	20		63	59	57	81	16	4

DAY 23

0	UNL	20		63	59	57	81	21	3
0	UNL	20		60	59	58	93	02	3
0	UNL	20		66	62	59	78	10	2
0	UNL	20		70	64	60	71	08	3
0	UNL	20		71	64	60	68	11	14
5	UNL	15		72	65	60	66	11	16
10	80	6	F	69	65	64	87	12	10
10	80	6	F	72	69	67	84	19	5

DAY 24

10	4	3	F	71	70	69	93	17	7
10	7	3	RF	72	71	70	93	18	10
10	8	8	R	71	70	70	97	20	12
10	12	9		78	74	72	82	28	10
5	33	9		86	74	69	55	30	14
3	UNL	10		89	72	64	45	30	18
5	UNL	10		82	70	64	55	33	13
1	UNL	10		75	66	60	60	32	13

DAY 25

01	0	UNL	15		67	59	54	63	32	11
04	0	UNL	15		63	56	54	73	30	8
07	0	UNL	25		66	57	50	57	31	12
10	1	UNL	25		71	57	46	41	34	13
13	3	UNL	25		74	59	47	33	31	12
16	3	UNL	25		76	59	45	33	31	15
19	0	UNL	25		70	57	46	42	36	10
22	0	UNL	20		65	55	46	50	34	6

DAY 26

0	UNL	20		61	54	49	65	29	7
0	UNL	20		59	54	49	70	30	8
0	UNL	20		65	55	49	55	28	7
2	UNL	15		74	53	47	33	28	10
3	UNL	15		78	61	48	35	26	13
6	250	20		80	62	49	34	25	9
8	250	20		73	64	58	59	21	14
1	UNL	15		70	63	58	66	23	14

DAY 27

7	80	15		68	61	56	66	23	15
4	UNL	15		67	62	59	76	23	11
9	90	12		70	63	59	68	25	15
8	UNL	12		92	70	53	53	23	11
8	45	8		86	71	64	48	25	15
7	250	8		85	72	65	51	23	16
8	100	7		79	72	68	69	20	16
6	110	7		75	70	68	79	24	14

DAY 28

01	4	UNL	6	H	73	70	68	84	27	9
04	2	UNL	4	H	71	68	67	87	28	7
07	0	UNL	8		74	68	65	74	30	7
10	2	UNL	12		82	69	62	51	35	7
13	8	UNL	12		86	70	61	43	30	10
16	6	300	12		75	67	63	66	12	10
19	8	UNL	10		73	67	64	74	13	5
22	6	UNL	10		70	66	63	79	08	6

DAY 29

7	UNL	10		69	65	63	81	02	5
8	110	10		68	61	57	68	04	8
9	100	15		69	63	59	71	07	9
9	100	15		73	66	61	66	08	7
10	100	15		70	64	60	71	09	9
10	80	13	RW	68	65	64	87	07	6
10	70	7	RW	67	66	66	97	08	9
10	60	4	F	67	66	66	97	07	7

DAY 30

10	10	4		F	66	65	65	97	10	10
10	7	4		F	66	65	65	97	10	13
10	5	4		F	66	65	65	97	07	10
10	3	1	8	RF	66	66	66	100	07	15
10	2	2		RF	67	66	66	97	08	6
10	3	1		F	67	66	66	97	01	10
10	6	4		F	67	66	66	97	01	7
10	4	2	9	LF	64	64	64	100	36	10

DAY 31

01	10	3	1	8	LF	64	64	64	100	36	13
04	10	3	3		LF	63	63	63	100	35	10
07	10	5	9		L	63	63	63	100	35	11
10	10	6	6		LF	63	62	62	97	35	15
13	10	9	6		FH	66	63	62	87	36	10
16	10	9	9			64	63	62	93	03	7
19	10	7	8			63	62	61	93	04	6
22	10	6	4		F	62	61	61	97	02	5

STATION

BOSTON MASS

YEAR & MONTH

76 07

A HAIL
F FOG
IF ICE FOG
GF GROUND FOG
BD BLOWING DUST
BN BLOWING SAND
BS BLOWING SNOW
BY BLOWING SPRAY
K SMOKE
H HAZE
D DUST

WIND

DIRECTIONS ARE THOSE FROM WHICH THE WIND BLOWS. INDICATED IN TENS OF DEGREES FROM TRUE NORTH: I.E., 09 FOR EAST, 18 FOR SOUTH, 27 FOR WEST. ENTRY OF 00 IN THE DIRECTION COLUMN INDICATES CALM.

SPEED IS EXPRESSED IN KNOTS: MULTIPLY BY 1.15 TO CONVERT TO MILES PER HOUR.

DAY 10 — DAY 11 — DAY 12

01	10	24	7		71	70	70	87	12	14	3	UNL	10		69	66	65	87	25	10	0	UNL	10		71	68	66	84	25	6
04	10	19	7	RW	72	70	69	90	16	27	2	UNL	10		66	65	65	97	24	8	0	UNL	10		69	66	65	87	24	6
07	10	11	6	LF	70	69	68	93	19	25	1	UNL	15		71	67	64	79	29	6	0	UNL	9		74	68	65	74	23	2
10	10	14	10	L	74	71	69	84	20	22	0	UNL	10		81	70	64	56	23	6	3	UNL	7		84	73	67	57	18	6
13	8	100	15		81	72	67	63	25	28	1	UNL	10		83	70	63	51	16	5	3	UNL	12		87	73	66	50	23	12
16	10	80	15		76	70	67	74	25	22	1	UNL	10		79	69	64	60	12	10	3	UNL	10		88	73	66	48	21	8
19	10	80	12	RW	72	69	67	84	25	15	1	UNL	12		75	68	64	68	15	6	5	UNL	6	H	78	72	69	74	20	9
22	7	120	12		71	68	66	84	25	14	0	UNL	10		73	69	67	82	24	7	0	UNL	6	H	75	70	67	76	23	18

DAY 13 — DAY 14 — DAY 15

01	8	UNL	5	H	73	68	56	78	22	12	5	UNL	4	H	72	70	69	[illegible]	[illegible]	4	8	7	2	FH	71	70	70	97	21	7
04	0	UNL	4	H	73	59	67	82	24	11	10	250	2	8 FH	72	71	70	93	[illegible]	[illegible]	10	5	2	RWFH	71	70	70	97	20	9
07	4	UNL	4	H	75	70	52	[illegible]	24	12	10	8	2	FH	74	72	71	90	25	3	10	60	4	FH	70	69	69	97	19	5
10	10	UNL	5	H	86	74	69	59	25	11	3	UNL	3	FH	81	74	71	72	[illegible]	5	3	UNL	5	H	78	73	71	79	21	14
13	2	UNL	6	H	89	76	70	54	25	14	10	250	4	FH	76	72	70	82	13	8	4	UNL	7		84	75	71	65	19	15
16	4	UNL	7		91	76	69	48	22	16	3	UNL	9		78	72	69	74	11	8	8	250	13		81	74	71	72	19	14
19	6	250	4	H	81	73	70	69	21	14	8	250	8		78	73	70	77	20	8	10	250	8		76	73	71	85	19	13
22	6	250	3	H	77	72	70	79	23	8	8	250	6	H	72	71	70	93	18	6	10	20	7	RW	75	72	71	87	22	11

DAY 16 — DAY 17 — DAY 18

01	10	60	5	RWF	70	69	68	93	28	10	0	UNL	20		63	57	53	70	29	10	6	55	15		66	61	57	73	35	9
04	10	50	12		69	66	64	84	27	9	0	UNL	15		60	57	54	81	30	8	1	UNL	15		63	58	55	75	36	10
07	9	UNL	15		68	63	60	76	30	11	0	UNL	15		63	57	53	70	28	10	1	UNL	15		66	60	55	68	03	11
10	6	UNL	15		73	65	60	64	29	15	3	UNL	15		72	62	55	55	35	6	0	UNL	15		71	64	59	66	04	16
13	4	UNL	15		76	63	54	48	29	16	3	UNL	15		78	65	57	48	27	17	1	UNL	15		74	64	57	55	05	18
16	4	UNL	15		75	63	54	48	29	13	5	UNL	15		80	65	56	44	35	7	1	UNL	15		68	61	56	66	06	14
19	2	UNL	20		70	60	53	55	30	14	3	UNL	15		76	64	57	52	35	8	2	UNL	15		64	58	56	75	07	6
22	2	UNL	20		67	59	53	61	28	11	0	UNL	15		71	63	57	61	34	9	0	UNL	15		62	58	56	81	08	5

DAY 19 — DAY 20 — DAY 21

01	0	UNL	15		59	57	55	87	35	7	0	UNL	15		60	55	51	72	24	4	0	UNL	12		73	67	63	71	29	7
04	0	UNL	15		58	56	55	90	35	11	0	UNL	15		59	55	51	75	24	6	0	UNL	12		72	66	62	71	29	7
07	2	UNL	15		63	58	54	73	03	9	0	UNL	15		63	58	55	75	29	5	0	UNL	15		74	66	62	68	29	7
10	5	UNL	15		72	60	52	50	02	14	0	UNL	12		77	66	59	54	24	8	0	UNL	15		84	72	66	55	29	5
13	8	250	15		71	61	53	53	11	12	5	UNL	15		85	68	58	40	29	3	0	UNL	12		91	75	68	47	25	6
16	6	UNL	15		67	61	57	70	08	12	7	UNL	15		82	68	59	46	13	8	0	UNL	10		91	76	70	50	29	5
19	6	UNL	15		63	58	55	75	12	7	2	UNL	15		82	68	59	46	30	7	1	UNL	8		79	73	70	74	15	4
22	0	UNL	15		61	55	51	70	25	4	0	UNL	15		77	68	63	62	27	5	7	UNL	6	H	83	75	71	67	29	6

DAY 22 — DAY 23 — DAY 24

01	0	UNL	6	H	80	74	72	77	32	5	3	UNL	5	H	80	76	75	85	30	6	2	UNL	10		69	65	62	79	34	8
04	3	UNL	5	H	76	73	72	87	29	4	0	UNL	7		79	73	71	77	31	8	0	UNL	12		65	60	57	75	34	9
07	0	UNL	6	H	80	73	70	72	36	3	0	UNL	6	H	78	71	68	71	33	8	0	UNL	15		67	61	57	70	36	11
10	0	UNL	6	H	85	76	72	65	14	5	6	UNL	7		82	72	67	61	08	8	0	UNL	15		73	64	58	59	07	9
13	0	UNL	7		86	75	70	59	13	8	1	UNL	5	H	81	72	67	63	09	14	2	UNL	15		72	63	58	62	10	13
16	5	UNL	8		85	74	69	59	11	6	10	46	4	H	75	70	68	79	07	6	0	UNL	15		72	63	57	59	09	10
19	8	UNL	6	H	81	74	71	72	18	6	0	UNL	6	H	72	67	65	79	09	4	2	UNL	15		69	61	56	63	14	7
22	10	UNL	4	H	81	76	74	79	24	9	2	UNL	7		72	67	65	79	36	4	0	UNL	15		66	60	55	68	21	6

DAY 25 — DAY 26 — DAY 27

01	0	UNL	15		65	62	60	84	24	10	0	UNL	10		70	67	65	84	12	2	10	8	2	8 FH	73	71	70	90	20	10
04	0	UNL	15		64	62	61	90	24	7	1	UNL	10		68	64	62	81	31	5	10	10	3	RWFH	72	71	70	93	11	5
07	4	UNL	13		69	63	60	73	28	9	10	200	12		70	64	61	73	33	3	10	50	2	9 RWF	71	70	69	93	22	8
10	0	UNL	15		73	64	54	42	31	7	6	UNL	11		75	57	63	66	14	7	10	12	4	FH	74	71	70	87	21	12
13	0	UNL	15		86	65	50	29	35	9	6	UNL	8		77	69	65	67	09	11	10	9	4	FH	71	68	67	87	20	10
16	3	UNL	15		88	67	54	31	29	8	10	UNL	8		77	71	68	74	12	11	10	15	6	H	74	70	68	82	19	6
19	5	UNL	12		72	67	65	78	12	4	4	UNL	8		76	70	67	74	18	8	10	30	6	H	73	70	68	84	20	11
22	0	UNL	10		70	66	63	79	14	3	10	4	1	FH	72	70	69	90	20	8	10	6	4	TRWFH	70	69	69	97	22	8

DAY 28 — DAY 29 — DAY 30

01	10	4	2	TRWF	70	69	69	97	19	11	10	17	4	H	74	71	70	87	20	8	0	UNL	15		61	54	48	63	29	11
04	10	8	2	8 F	71	70	70	97	22	7	9	15	3	H	72	71	70	93	22	7	0	UNL	15		58	52	47	67	30	10
07	10	12	1	8 F	72	71	70	93	20	9	10	9	3	FH	73	71	70	90	19	9	0	UNL	15		57	49	41	55	30	15
10	10	11	3	F	75	72	71	87	23	10	10	21	4	H	79	73	71	77	23	12	2	UNL	15		61	52	43	52	28	16
13	6	30	4	H	82	75	72	72	22	11	8	35	4	H	82	75	72	72	20	15	2	UNL	15		65	54	44	47	31	16
16	7	30	4	H	82	76	73	74	20	10	8	50	8		74	71	70	87	22	5	6	40	15		63	53	43	48	30	17
19	4	UNL	4	H	74	72	71	90	19	9	7	250	10		75	68	64	69	30	16	0	UNL	15		58	50	43	58	33	11
22	10	10	4	H	74	71	70	87	23	11	6	70	10		68	59	52	57	30	17	0	UNL	15		56	50	44	64	29	8

DAY 31

01	0	UNL	15		54	48	43	67	29	9
04	0	UNL	15		51	46	41	69	29	9
07	0	UNL	15		52	47	41	66	29	7
10	0	UNL	15		62	51	38	43	31	10
13	0	UNL	15		69	54	40	35	27	11
16	0	UNL	20		72	57	44	37	24	8
19	0	UNL	20		68	56	46	45	25	9
22	2	UNL	20		63	58	50	63	24	8

STATION

BOSTON MASS

YEAR & MONTH

76 08

[illegible]

F FOG
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DAY 10

01	1	UNL	12		59	57	55	87	22	7
04	1	UNL	12		59	57	56	90	19	4
07	9	UNL	12		62	60	59	90	16	4
10	6	24	12		70	65	62	76	15	9
13	10	18	10		71	66	63	76	16	12
16	10	17	8		68	64	62	81	12	8
19	10	11	7		69	66	65	87	14	14
22	10	10	6	RWF	69	67	66	90	19	12

DAY 11

01	10	33	8	RW	63	60	58	84	30	14
04	10	70	8	RW	60	58	56	87	24	8
07	5	UNL	12		60	57	55	84	25	6
10	6	70	15		66	56	48	52	27	8
13	4	UNL	15		70	58	49	47	24	11
16	3	UNL	15		70	56	45	41	22	11
19	1	UNL	15		64	55	47	54	23	12
22	8	80	15		61	55	50	67	20	7

DAY 12

01	3	UNL	15		59	53	48	67	25	10
04	0	UNL	15		57	52	47	69	27	11
07	0	UNL	15		57	51	46	67	29	13
10	1	UNL	15		66	55	46	49	31	11
13	1	UNL	15		70	57	47	44	34	12
16	0	UNL	15		72	59	46	40	29	9
19	0	UNL	15		68	57	47	47	31	7
22	0	UNL	15		61	55	51	70	24	4

DAY 13

01	1	UNL	20		60	56	52	75	24	5
04	0	UNL	20		61	56	52	72	29	6
07	10	UNL	12		63	59	54	73	30	5
10	10	UNL	12		72	62	55	55	32	4
13	10	250	12		78	65	57	49	00	0
16	10	UNL	12		82	69	60	47	24	9
19	10	UNL	12		75	67	62	64	24	9
22	0	UNL	12		68	63	60	76	24	5

DAY 14

01	0	UNL	13		66	62	59	78	23	5
04	0	UNL	12		63	60	58	84	22	3
07	5	UNL	10		65	61	58	78	13	4
10	1	UNL	10		81	67	59	47	24	5
13	1	UNL	12		86	69	59	40	23	7
16	9	UNL	13		85	68	58	40	25	13
19	6	UNL	12		74	66	62	66	20	7
22	2	UNL	11		71	65	61	71	24	9

DAY 15

01	2	UNL	7		69	63	60	73	24	7
04	0	UNL	7		65	61	59	81	22	5
07	10	UNL	4	H	67	63	60	78	21	4
10	10	250	5	H	75	67	62	62	23	6
13	10	100	5	H	79	69	64	60	23	3
16	10	120	8		78	67	60	54	23	11
19	10	100	7		74	66	62	66	24	8
22	10	200	7		69	65	62	79	24	9

DAY 16

01	10	250	7		67	64	62	84	22	5
04	6	UNL	7		65	63	61	87	22	8
07	10	120	7		67	64	62	84	24	6
10	10	120	11		74	66	62	66	23	5
13	10	23	3	F	69	64	61	76	06	9
16	10	120	4	FH	65	61	59	81	08	8
19	10	50	3	FH	63	61	59	87	35	2
22	10	1	0	6 F	60	59	59	97	07	3

DAY 17

01	10	3	1	12 F	63	61	60	93	05	5
04	10	3	1	12 F	63	61	60	90	03	5
07	10	3	0	12 RF	63	62	61	93	05	7
10	10	2	0	4 RLF	65	64	63	93	05	7
13	10	11	1	F	68	66	65	90	04	10
16	10	1	0	8 RF	65	64	64	97	07	9
19	10	2	0	12 F	66	65	64	93	35	5
22	10	0	0	1 F	65	64	64	97	05	2

DAY 18

01	10	1	0	1 LF	63	63	63	100	08	5
04	10	23	2	9 F	64	63	63	97	07	1
07	7	250	1	F	66	64	63	90	11	3
10	9	250	6	H	74	69	67	79	19	9
13	3	UNL	10		80	68	61	52	22	15
16	1	UNL	10		79	67	60	52	20	15
19	9	80	10		71	66	63	76	20	8
22	9	90	10		69	65	62	79	23	8

DAY 19

01	4	UNL	7		66	63	61	84	24	8
04	7	80	7		64	62	60	87	24	6
07	0	UNL	6	H	65	62	60	84	26	5
10	4	UNL	10		73	64	59	62	32	8
13	5	UNL	12		77	66	59	54	30	8
16	3	UNL	15		78	66	59	52	32	11
19	0	UNL	15		72	64	59	64	24	5
22	0	UNL	15		70	64	60	71	29	7

DAY 20

01	0	UNL	15		69	63	59	71	28	9
04	0	UNL	15		65	60	56	73	28	11
07	10	UNL	12		66	59	53	63	27	6
10	2	UNL	12		74	64	58	58	27	6
13	4	UNL	12		81	67	58	46	24	22
16	7	250	15		80	66	58	47	23	13
19	10	250	12		72	65	61	68	20	10
22	10	70	8	RW	70	64	60	71	23	12

DAY 21

01	10	50	4	RWF	67	64	63	87	23	8
04	0	UNL	4	GF	65	64	63	93	22	9
07	10	80	2	9 F	66	63	62	87	24	7
10	8	20	5	F	72	65	61	68	25	9
13	5	UNL	12		73	63	57	57	31	13
16	10	120	15		69	60	53	57	32	10
19	10	80	15		67	58	51	57	31	9
22	10	70	15		64	55	48	56	33	11

DAY 22

01	6	70	15		59	53	47	65	33	9
04	0	UNL	15		54	49	45	72	33	6
07	0	UNL	15		57	51	45	64	36	6
10	0	UNL	15		62	55	49	63	14	8
13	8	30	12	TRW	67	56	46	47	23	12
16	2	UNL	15		66	54	43	43	27	13
19	8	45	15		63	53	43	48	27	7
22	0	UNL	15		57	50	44	62	26	9

DAY 23

01	0	UNL	15		56	47	38	51	28	13
04	0	UNL	15		52	45	38	59	24	12
07	0	UNL	15		52	46	40	64	25	10
10	0	UNL	15		61	50	38	43	23	12
13	1	UNL	15		69	55	43	39	23	14
16	0	UNL	15		69	57	46	44	20	16
19	3	UNL	15		63	56	50	63	20	12
22	3	UNL	15		62	57	54	75	19	13

DAY 24

01	7	250	15		64	60	58	81	24	9
04	7	80	15		61	52	44	54	29	10
07	10	80	15		57	46	33	40	31	6
10	7	250	20		58	47	35	42	28	8
13	7	250	20		66	51	35	32	35	3
16	4	UNL	20		64	51	37	37	12	8
19	0	UNL	20		57	51	46	67	13	8
22	0	UNL	20		56	48	40	55	30	8

DAY 25

01	0	UNL	20		51	45	38	61	32	7
04	0	UNL	20		48	43	37	66	33	8
07	0	UNL	20		50	45	39	66	31	5
10	0	UNL	20		61	51	42	50	25	5
13	0	UNL	20		65	52	38	35	30	10
16	1	UNL	20		68	53	39	33	28	12
19	0	UNL	20		62	50	38	41	27	3
22	2	UNL	20		58	52	47	67	24	8

DAY 26

01	0	UNL	20		54	50	47	77	22	4
04	2	UNL	15		53	50	47	80	36	2
07	8	250	12		55	53	50	80	22	3
10	9	250	15		61	55	52	72	12	4
13	9	UNL	15		70	59	51	51	20	10
16	10	80	15		65	56	48	54	18	12
19	10	38	12	R	60	57	55	84	15	12
22	10	30	12	R	61	59	58	90	15	7

DAY 27

01	10	65	6	RF	66	64	63	90	21	13
04	10	49	6	RF	65	63	61	87	19	12
07	10	200	10		67	65	64	90	23	12
10	10	24	12		73	67	64	74	25	13
13	10	36	10		73	67	64	74	25	10
16	10	46	5	RWF	70	67	65	84	21	7
19	10	9	3	RF	68	67	66	93	34	10
22	10	12	11	R	60	59	58	93	01	10

DAY 28

01	10	8	10	R	57	55	54	90	35	10
04	10	10	10		56	55	54	93	36	10
07	10	31	13		56	54	52	87	32	8
10	3	UNL	15		63	55	49	60	31	12
13	6	45	15		65	54	44	47	31	12
16	3	UNL	15		62	51	40	45	32	10
19	2	UNL	15		57	49	41	55	02	5
22	0	UNL	15		52	46	39	61	36	4

DAY 29

01	0	UNL	15		49	44	39	69	34	4
04	0	UNL	15		47	44	40	77	30	6
07	0	UNL	13		49	45	40	71	27	8
10	0	UNL	15		57	47	37	47	27	12
13	0	UNL	15		64	52	41	43	24	13
16	0	UNL	15		65	53	41	42	24	18
19	0	UNL	15		59	51	44	58	25	10
22	0	UNL	15		55	50	45	69	23	10

DAY 30

01	0	UNL	15		55	50	45	69	24	10
04	0	UNL	15		53	49	45	74	25	9
07	1	UNL	13		56	50	45	67	24	6
10	7	250	12		65	56	49	56	30	8
13	10	100	12		66	57	50	57	33	5
16	10	100	10		62	56	52	70	12	6
19	10	80	7		60	57	54	81	14	6
22	10	80	7		59	56	53	81	13	2

A HAIL
F FOG
IF ICE FOG
GF GROUND FOG
BD BLOWING DUST
BN BLOWING SAND
BS BLOWING SNOW
BY BLOWING SPRAY
K SMOKE
H HAZE
D DUST

WIND

DIRECTIONS ARE THOSE FROM WHICH THE WIND BLOWS. INDICATED IN TENS OF DEGREES FROM TRUE NORTH: I.E., 09 FOR EAST, 18 FOR SOUTH, 27 FOR WEST. ENTRY OF 00 IN THE DIRECTION COLUMN INDICATES CALM.

SPEED IS EXPRESSED IN KNOTS; MULTIPLY BY 1.15 TO CONVERT TO MILES PER HOUR.

STATION

BOSTON MASS

YEAR & MONTH

76 09

DAY 10

01	8	110	7			72	65	61	68	19	5
04	2	UNL	6		H	70	64	60	71	23	8
07	1	UNL	9		H	74	66	61	64	22	5
10	0	UNL	3		H	81	70	64	56	15	6
13	2	UNL	6		H	92	74	65	41	23	12
16	3	UNL	9			92	72	61	36	24	15
19	0	UNL	7			86	72	65	50	24	15
22	0	UNL	7			79	68	62	56	24	13

DAY 11

01	0	UNL	7			74	65	60	62	24	13
04	0	UNL	5		H	73	66	62	69	24	10
07	3	UNL	4		H	77	68	63	62	25	11
10	0	UNL	6		H	88	70	61	40	27	11
13	4	UNL	5		H	92	69	56	30	25	13
16	4	UNL	5		H	91	69	56	31	24	20
19	10	70	5		H	86	68	58	39	25	11
22	5	UNL	4		H	81	67	59	47	26	13

DAY 12

01	8	70	5		H	76	67	61	60	31	15
04	1	UNL	12			70	64	60	71	31	13
07	0	UNL	15			63	54	45	52	33	16
10	8	35	20			65	54	45	49	36	10
13	6	45	20			65	54	44	47	09	16
16	8	UNL	20			63	54	45	52	08	20
19	10	UNL	20			59	51	43	56	12	6
22	8	UNL	20			57	50	43	60	21	4

DAY 13

01	0	UNL	20			55	43	41	57	25	4
04	[illegible]	UNL	20			54	[illegible]	42	54	24	3
07	[illegible]	UNL	20			[illegible]	[illegible]	42	52	25	3
10	[illegible]	UNL	20			67	54	[illegible]	[illegible]	13	11
13	2	UNL	20			71	57	45	39	20	13
16	3	UNL	20			72	59	46	40	18	17
19	10	UNL	20			65	54	45	49	20	16
22	10	UNL	20			61	53	45	56	23	15

DAY 14

01	10	UNL	15			60	55	50	70	22	13
04	10	UNL	15			61	57	54	78	23	13
07	10	UNL	15			65	60	55	70	21	14
10	10	20	12			71	64	59	66	24	19
13	10	24	10			77	67	61	58	27	14
16	10	UNL	9			79	68	62	56	24	12
19	10	UNL	6		H	74	66	62	66	24	17
22	8	UNL	7			70	63	59	68	24	16

DAY 15

01	10	UNL	9			68	63	59	73	24	15
04	10	250	8			70	64	60	71	22	15
07	10	100	9			73	66	62	69	26	17
10	7	250	7			81	70	64	56	22	14
13	7	UNL	9			83	73	65	45	22	18
16	7	UNL	7			88	73	66	48	21	13
19	2	UNL	6		H	85	73	67	55	24	14
22	3	UNL	5		H	76	70	67	74	24	13

DAY 16

01	3	UNL	4		H	74	69	67	79	23	11
04	3	UNL	3		H	73	68	66	79	23	12
07	3	UNL	5		H	76	70	67	74	22	16
10	4	UNL	6		H	88	75	69	53	23	15
13	7	250	9			93	74	64	38	22	20
16	9	UNL	10			86	73	67	53	19	17
19	10	250	12			77	70	67	71	20	16
22	10	250	12			75	69	66	74	22	18

DAY 17

01	10	18	10			76	70	67	74	23	12
04	10	80	10			75	69	66	74	23	12
07	10	46	9		RW	74	69	67	79	24	10
10	10	20	13			77	70	66	69	26	11
13	8	35	15			82	71	65	56	29	7
16	9	100	15			84	71	65	53	24	8
19	8	UNL	10			80	72	68	67	23	13
22	0	UNL	8			75	69	66	74	25	10

DAY 18

01	4	UNL	6		H	71	68	66	84	24	5
04	3	UNL	5		H	72	67	64	76	29	8
07	0	UNL	10			75	65	59	59	33	5
10	4	UNL	11			78	68	62	58	09	9
13	6	250	12			74	65	60	62	08	13
16	6	30	7			75	66	61	62	11	16
19	3	UNL	12			79	71	67	67	19	10
22	0	UNL	7			73	69	67	82	21	12

DAY 19

01	0	UNL	7			71	68	66	84	18	6
04	10	18	9			70	67	66	87	19	8
07	10	UNL	12			76	70	67	74	22	8
10	9	24	12			81	71	66	60	19	10
13	8	24	12			80	73	69	69	21	10
16	9	24	12			80	73	69	69	17	11
19	10	10	10			75	71	69	82	17	10
22	10	7	7			74	71	69	84	17	9

DAY 20

01	10	7	8			72	70	69	90	19	10
04	10	6	10			71	69	68	90	19	10
07	10	6	9			73	70	68	84	21	9
10	10	6	10			78	72	69	74	20	13
13	10	80	10			85	75	70	61	20	14
16	9	20	12			81	73	69	67	19	14
19	5	UNL	8			76	71	69	79	20	12
22	8	8	7			73	69	67	82	24	12

DAY 21

01	8	14	10			73	70	68	84	20	8
04	10	9	10			73	70	68	84	19	7
07	10	10	9			76	71	69	79	23	10
10	10	20	10			83	73	69	63	25	14
13	5	UNL	10			90	74	66	45	20	11
16	5	UNL	10			86	73	67	53	20	16
19	3	UNL	10			79	72	68	69	20	12
22	5	UNL	8			73	70	68	84	20	10

DAY 22

01	9	15	10			72	69	67	84	18	7
04	5	UNL	10			71	68	67	87	18	7
07	10	16	12			77	71	68	74	22	12
10	9	140	12			84	73	67	57	24	9
13	5	UNL	15			88	73	66	48	28	15
16	4	UNL	15			90	74	67	47	24	15
19	0	UNL	15			84	73	67	57	23	14
22	0	UNL	12			76	71	69	79	22	10

DAY 23

01	1	UNL	12			73	70	68	84	23	12
04	0	UNL	12			70	67	65	84	24	11
07	1	UNL	12			75	69	65	71	24	12
10	3	UNL	15			86	71	64	48	23	13
13	7	250	15			90	73	64	42	27	10
16	5	UNL	15			90	73	65	44	25	9
19	10	55	14			84	74	69	61	23	15
22	7	90	8			79	72	69	72	24	11

DAY 24

01	0	UNL	9			75	71	69	82	24	10
04	0	UNL	8			74	71	69	84	26	7
07	0	UNL	6		H	80	73	69	69	24	6
10	1	UNL	7			90	75	68	48	25	8
13	1	UNL	7			94	75	67	41	28	8
16	2	UNL	10			94	74	64	37	25	11
19	10	220	9			86	74	69	57	24	13
22	10	200	7			80	73	69	69	24	12

DAY 25

01	10	UNL	8			78	71	68	71	23	8
04	10	80	8		RW	76	71	68	76	24	9
07	10	50	8			75	71	69	82	19	9
10	8	UNL	10			83	73	68	61	25	20
13	10	35	10			88	74	68	52	25	20
16	10	UNL	10			88	72	64	45	28	19
19	10	70	14			80	71	66	62	32	12
22	10	UNL	14			77	69	64	64	30	10

DAY 26

01	10	UNL	12			73	67	84	74	26	5
04	8	250	12			71	67	64	79	26	6
07	10	150	10			78	69	64	62	27	12
10	3	UNL	10			86	71	63	46	30	13
13	9	UNL	10			72	66	62	74	28	13
16	10	3	3		F	66	63	62	87	09	14
19	10	2	0	6	LF	63	62	62	97	08	7
22	10	2	0	6	LF	62	61	61	97	06	4

DAY 27

01	10	2	1	2	LF	62	61	60	93	08	5
04	10	1	1	2	LF	60	59	59	97	10	5
07	10	2	2		F	52	61	60	93	14	5
10	1	UNL	10			63	63	60	73	07	10
13	3	65	3		F	65	62	60	84	11	13
16	10	65	10			65	62	60	84	13	10
19	3	UNL	12			63	61	59	87	09	7
22	3	UNL	9			61	59	58	90	15	5

DAY 28

01	10	2	4		F	64	62	61	90	24	1
04	10	5	2		LF	65	63	62	90	25	9
07	10	11	5		H	69	65	62	79	24	8
10	5	UNL	6		H	76	68	63	64	13	7
13	3	UNL	10			81	69	63	54	13	10
16	2	UNL	13			88	72	63	43	19	14
19	8	UNL	11			82	71	66	58	23	13
22	10	250	10			78	69	64	62	24	13

DAY 29

01	7	250	10			75	65	58	56	26	9
04	10	50	10			73	64	59	62	20	9
07	10	80	7		RW	71	65	62	73	28	17
10	10	70	7			70	67	65	84	21	6
13	10	180	10			81	70	65	58	23	13
16	4	UNL	6		H	85	72	65	51	19	12
19	10	UNL	8			78	71	68	71	18	9
22	0	UNL	6		H	72	69	68	87	19	6

DAY 30

01	1	UNL	5		H	69	67	66	90	18	4
04	6	5	2		FH	69	67	66	90	24	3
07	9	250	2	8	H	74	70	68	82	24	6
10	10	250	4		H	75	70	67	76	09	10
13	10	250	3		H	73	68	66	79	07	11
16	10	20	3		H	72	67	65	79	05	9
19	10	30	4		H	70	67	65	84	03	7
22	10	1	0	8	F	66	65	64	93	06	10

A	HAIL
F	FOG
IF	ICE FOG
GF	GROUND FOG
BD	BLOWING DUST
BN	BLOWING SAND
BS	BLOWING SNOW
BY	BLOWING SPRAY
K	SMOKE
H	HAZE
D	DUST

WIND

DIRECTIONS ARE THOSE FROM WHICH THE WIND BLOWS. INDICATED IN TENS OF DEGREES FROM TRUE NORTH; I.E., 09 FOR EAST, 18 FOR SOUTH, 27 FOR WEST. ENTRY OF 00 IN THE DIRECTION COLUMN INDICATES CALM.

SPEED IS EXPRESSED IN KNOTS; MULTIPLY BY 1.15 TO CONVERT TO MILES PER HOUR.

STATION

BOSTON MASS

YEAR & MONTH

76 06

IF AVERAGE SUMMER 'NIGHT TEMPERATURES' ARE 64°F, ALL THREE STRUCTURES CAN UNLOAD ALL OF THEIR DAYTIME STORED HEAT. [U VALUE OF MASS TO VENTED AIR = 1.5]

* -1° F FOR HEAVIEST BUILDING OF THIS REPORT = -35,200 BTUS
* STARTING TEMPERATURE OF HEAVIEST BUILDING = 74.3°F

U × A × ΔT = MASS HEAT LOSS

1ST HOUR	(1.5) × (3000 ϕ) × (10°F)	=	45,000 BTU	=	-1.3°F
2ND	(1.5) × (3000ϕ) × (9°F)	=	40,500 BTU	=	-1.15°F
3RD	(1.5) × (3000 ϕ) × (8.55°F)	=	38,475 BTU	=	-1.09°F
4TH	(1.5) × (3000 ϕ) × (7.46°F)	=	33,570 BTU	=	-.954°F
5TH	(1.5) × (3000 ϕ) × (6.5°F)	=	29,277 BTU	=	-.83°F
6TH	(1.5) × (3000ϕ) × (5.7°F)	=	25,515 BTU	=	-.724°F

6 HR. TOTAL = -6.05°F

* THE PROBABILITY OF THE HEAVIEST STRUCTURE GAINING MORE THAN 5°F DURING AN ENTIRE SUMMER IS LOW.

VI COMBINED GUIDELINES

This chapter combines and orders the guidelines of the preceding chapters.

The hard guidelines are quantified and therefore easily ranked. The soft guidelines are personal and represent only my viewpoint.

Because people have different values and personalities, readers will disagree with my final set. Never-the-less, I hope they will agree to the necessity of an explicit combined understanding of the hard and soft issues.

HARD GUIDELINES

Chart 6.1 displays the cost reductions possible by the various techniques of passive solar design.

Independence of Hard Objectives

Perhaps the most important conclusion of this thesis is that the objectives in Chart 6.1 can be dealt with independently.

Building shape does not affect optimal window area or material choices. Material choices do not affect building shape or optimal window area. Landscaping doesn't affect any of the other objectives. This independence allows a designer to approach each hard objective separately.

When totaling combined savings, however, the other issues must be considered. Cost reductions dealing with the same mechanical system may not be evaluated to determine its cumulative effect.

SOFT GUIDELINES

This ordered list is a combination of the soft guidelines of the preceeding 4 chapters:

1) Keep living and working space within 30' of windows.

2) Provide a full range of lighting effects in each living and working unit.

3) Choose shape, orientation, and crenelation to fit surrounding neighborhood.

4) Reinforce lighting effects with color and texture choices.

5) Vary views: short, long, multi-directional.

6) Design complete order of heavy building.

7) Design covers and screens.

8) Provide one special light-

CHART 6.1 — COMBINED HARD OBJECTIVES

OBJECTIVE	APARTMENT 5 year energy savings %	APARTMENT first cost savings %	APARTMENT adjusted first cost savings %	OFFICE 5 year energy savings %	OFFICE first cost savings %	OFFICE adjusted first cost savings*%
HAVE CRENELATION	5.1	21.0	26.1	1.5	21.1	22.6
HAVE SHAPE	5.1	21.0	26.1	1.0	21.1	22.1
USE DOUBLE VS SINGLE GLASS	2.4	5.2	7.6	1.0	3.1	4.1
BUILD HEAVILY 160#/ф VS 40#/ф	3.4	3.8	7.2	3.3	3.5	6.8
PROVIDE SUNSHADES	1.9	1.4	3.3	.9	2.3	3.2
USE TRIPLE GLASS VS DOUBLE	2.4	.9	3.3	.5	1.5	2.0
REDUCE WINDOW AREA 10% (FROM 30%)	1.3	1.4	2.7	.6	2.2	2.8
BUILD HEAVILY 80#/ф VS. 40#/ф	2.1	.4	2.5	.9	1.5	2.4
USE 80% VS. 50% REFLECTANCE ON OFFICE WALLS	—	—	—	2.6	3	5.6
OPTIMIZE PLAN GEOMETRY	.7	1.7	2.4	1.5	1.7	3.2
USE INSULATED SHUTTERS	1.2	.1	1.3	.4	-.2	.2
USE REFLECTIVE GLASS (EXCLUDING SOUTH)	.2	1	1.2	.1	2.7	2.3
USE WHITE GROUND VS. GRASS	.2	.1	.3	.2	.2	.4

*Technique for including operation in first cost.
See Chapter I for explanation.

ing effect per unit.

COMBINED GUIDELINES

The following represents my personal stand on where the soft objectives of passive solar design fit into the hard objectives of mechianical efficiency.

1) Minimize exterior surface area.

2) Keep living and working area within contact distance from windows.

3) Provide a full range of lighting effects in each living and working unit.

4) Choose shape, orientation and crenelation to fit neighforhood setting.

5) Build as heavily as possible.

6) Reinforce light.

6) Reinforce lighting effects with color and texture choices.

7) Provide sunshades.

8) Provide variety of views: long, short, multi-directional.

9) Design complete order of heavy building.

10) Design covers and screens.

11) Reduce glass area.

12) Use high reflectances in offices.

13) Optimize plan geometry.

14) Provide one special lighting effect per unit.

15) Use interior shutters.

16) Use reflective glass.

17) Use light ground covers.

VII TEST CASE

Chapter VII is the proof of my work to this point. I've selected for a test problem a project presently under construction in Boston. My task has been to develop my own plans to compare with those of the project being constructed for the purpose of estimating the human and economic costs of my sunlight theories.

The project combines all the trade-offs I've been investigating in a real situation.

One hundred and fifty housing units are being built on a 50,000 sq. ft. plot in Boston's revitalized wharf area. The economics of the project are typical of what American architects will be faced with in the near future. The project is government financed, 236 housing for the elderly.

Architecturally, the problem is especially interesting. It is located at the edge of Boston's North End among some of the finest old brick and stone buildings in this country and will be highly visible because it fronts Boston's new waterfront park.

First Costs

The first costs of mechanical equipment for the real project are 60% higher than those used for the report.[1] This is most likely due to the difference in local prices compared to the national averages used for the preceeding report. All first cost reductions developed in the report may be increased by 60% for determining test case savings.

Operating Costs

In this particular case the community has forced the developer to assume ownership of this building through the 20 year mortgage. The 'five-year energy' savings of this thesis may therefore be multiplied by 4 for computing test case savings.

---

[1] Chart 1.1 Figure

Program:

120 1br unit @ 650	78,000
30 2br unit @ 800	24,000
commercial first floor	20,000
community spaces	7,000
parking 10%	15 cars
	122,000

Consultants:

Both architect and developer of the real project have served as my consultants for this test case.

Evaluation:

Mechanical costs of my test project have been compared to those for the real project. The results are listed in the price tags in the upper right hand corner of each board.

My soft quidelines are built

CHART 7.1 MECHANICAL COST MULTIPLIERS

FIRST COST	APARTMENT	COMMERCIAL - OFFICE
HEATING	8%	13%
AIR CONDITIONING	5%	13%
LIGHTING	1%	9%

ENERGY BILL	$.80 /$ YR APARTMENT	$1.00/$ YR COMMERCIAL - OFFICE
HEATING	60%	20%
AIR CONDITIONING	30%	25%
LIGHTING	10%	50%

into the test project itself. Each reader must judge whether the quality of the spaces created is improved or reduced in comparison to the real project.

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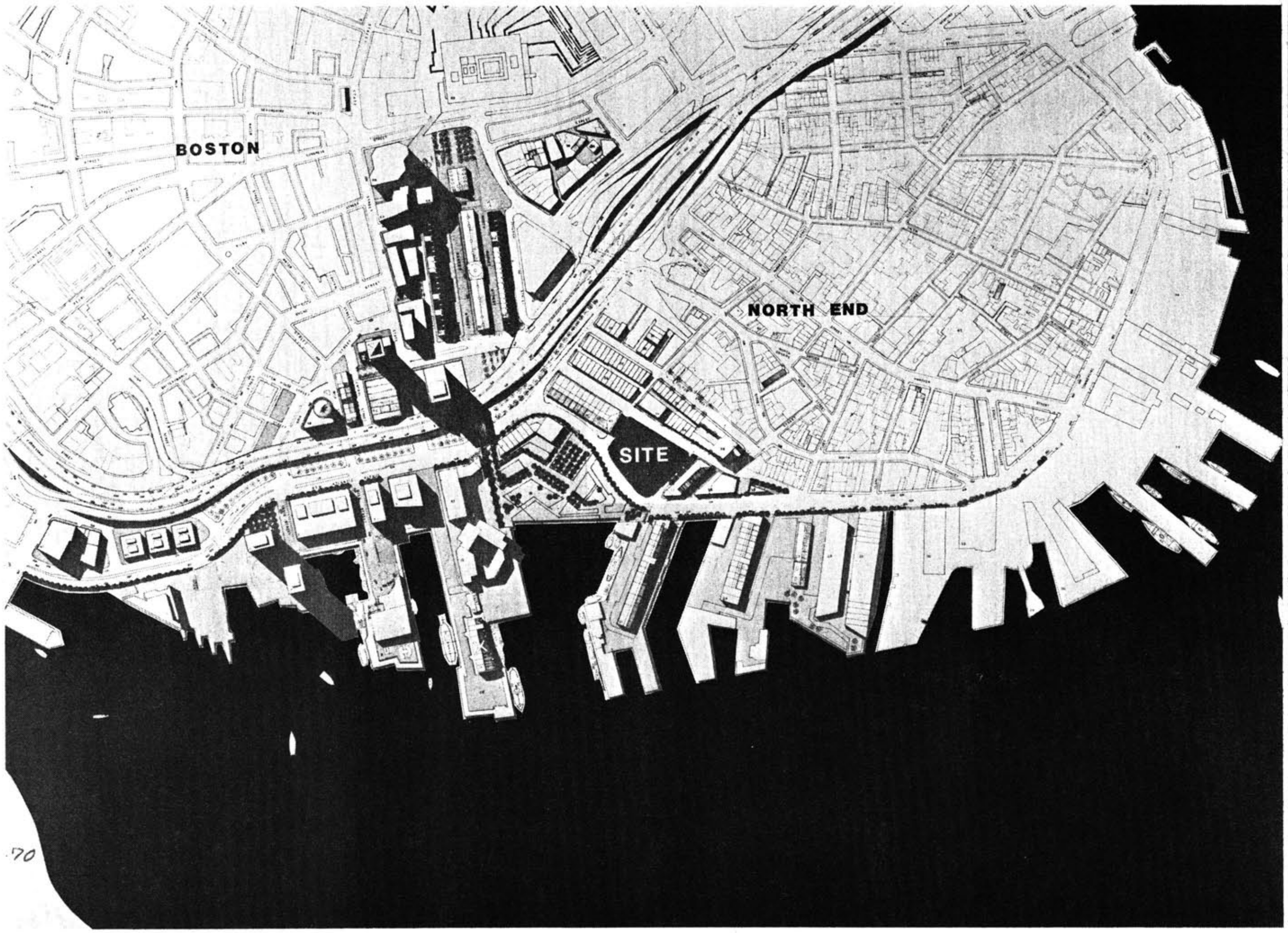


SITE

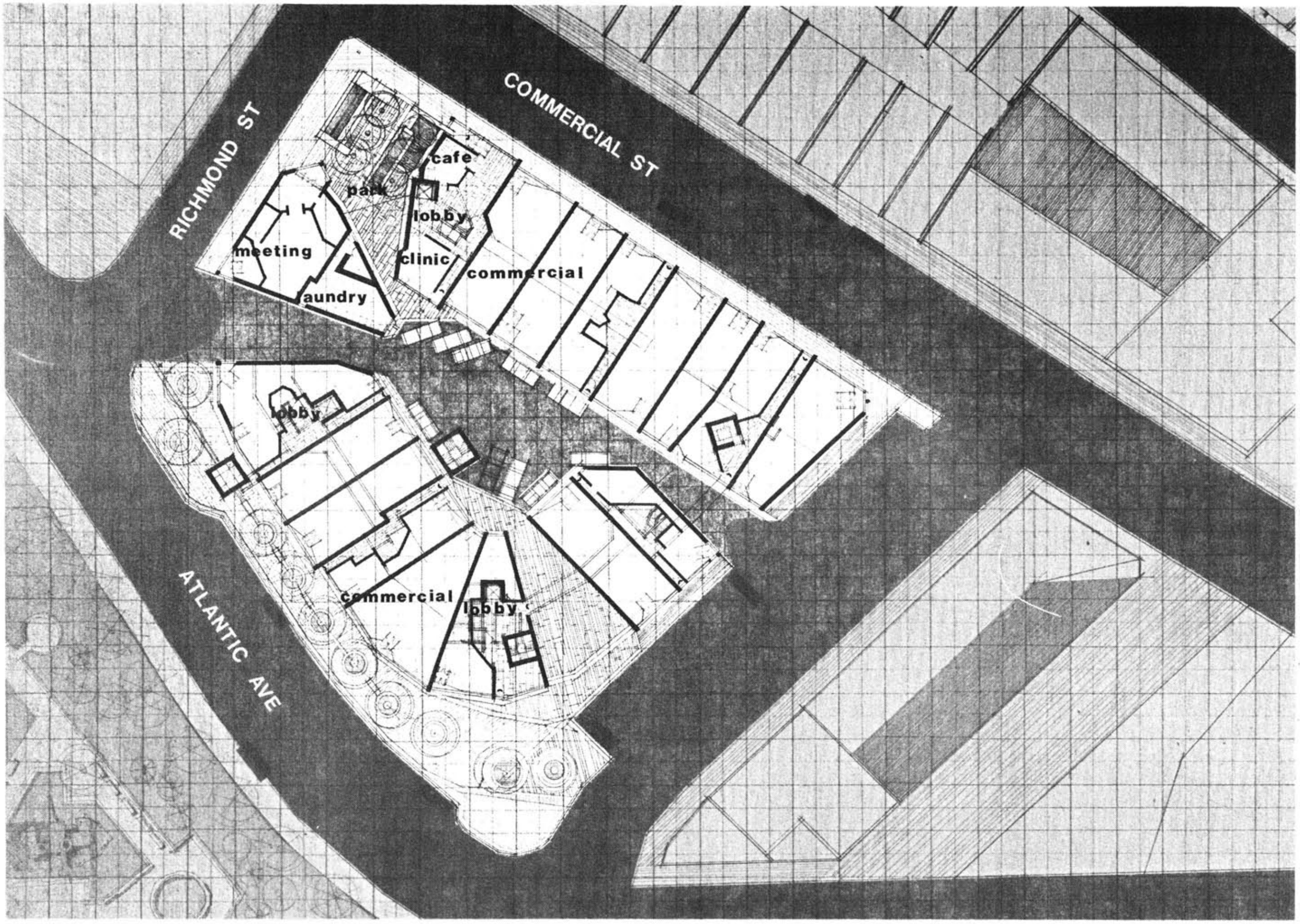
PARCEL C2B

PASSIVE ENERGY TEST SITE

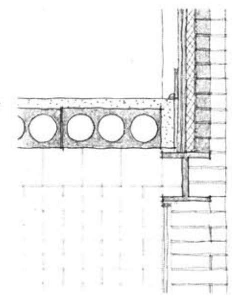
16 NORTH ST.
BOSTON MA.

JOHN MEYER THESIS SPRING 77

1



MINE VS THEIRS	% COST REDUCTION	
WHITE GROUND COVER VS. DARK BRICK	APARTMENT	OFFICE
1ST COST	0	0
5YR ENERGY	.2	.1
TOTAL	.2	.1
20YR ENERGY	.8	.4
20YR TOTAL	.8	.4



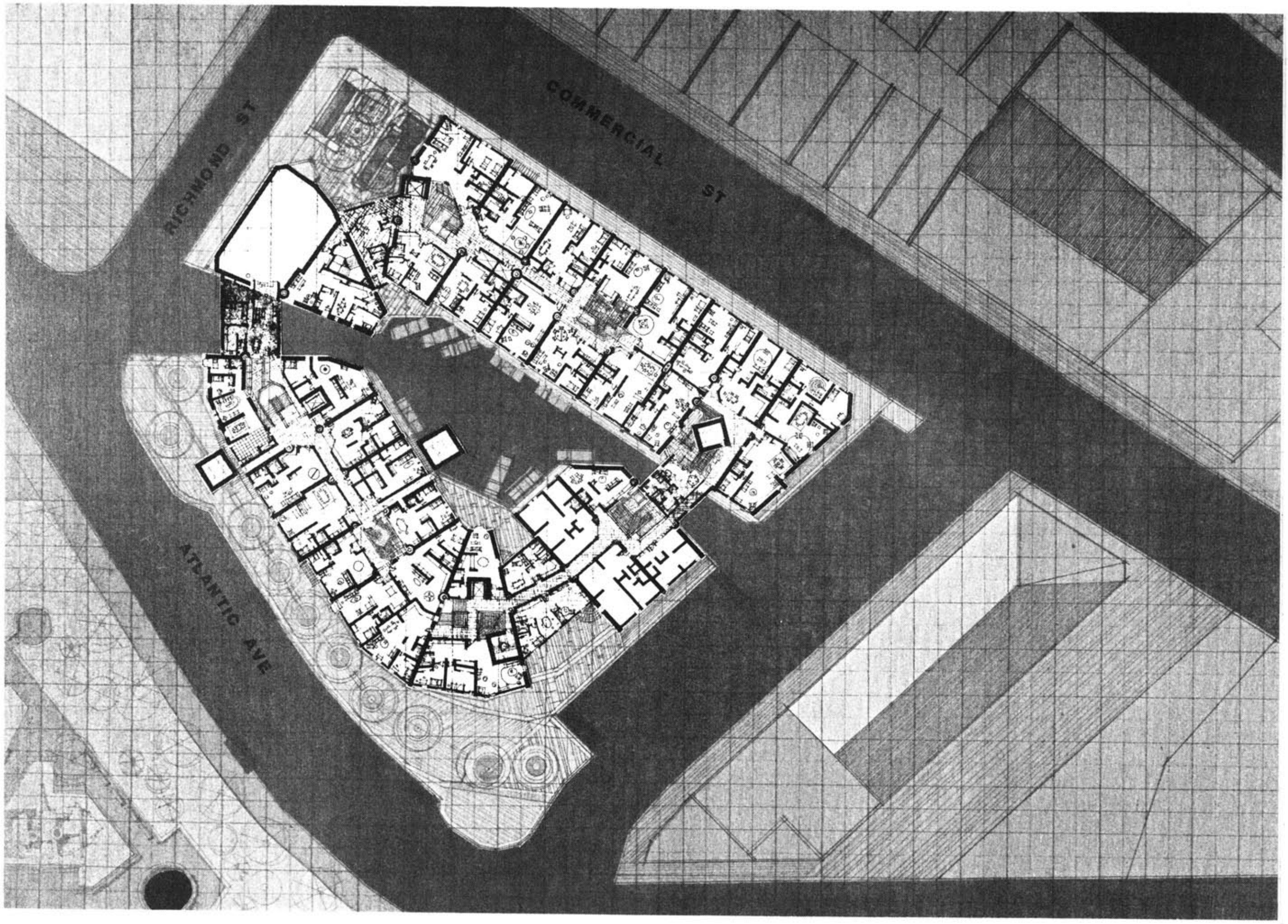
PARCEL C2B

PASSIVE ENERGY TEST SITE

16 NORTH ST.
BOSTON MA.

GROUND LEVEL PLAN

JOHN MEYER THESIS SPRING 77



MINE VS THEIRS

SURFACE AREA (WALLS ONLY)

65,250 φ [12% w/o [illegible]] vs. 74,250 φ

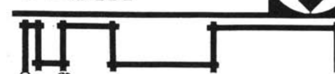
	% COST REDUCTION	
	APARTMENT	OFFICE
1ST COST	8.4	
5 YR ENERGY	1.4	
TOTAL	9.8	
✻ 20 YR ENERGY	5.6	
20 YR TOTAL	14.0	

PARCEL C2B

PASSIVE ENERGY TEST SITE

16 NORTH ST.
BOSTON MA.

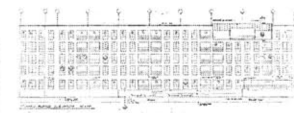
3rd LEVEL PLAN

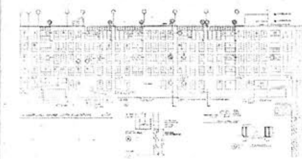


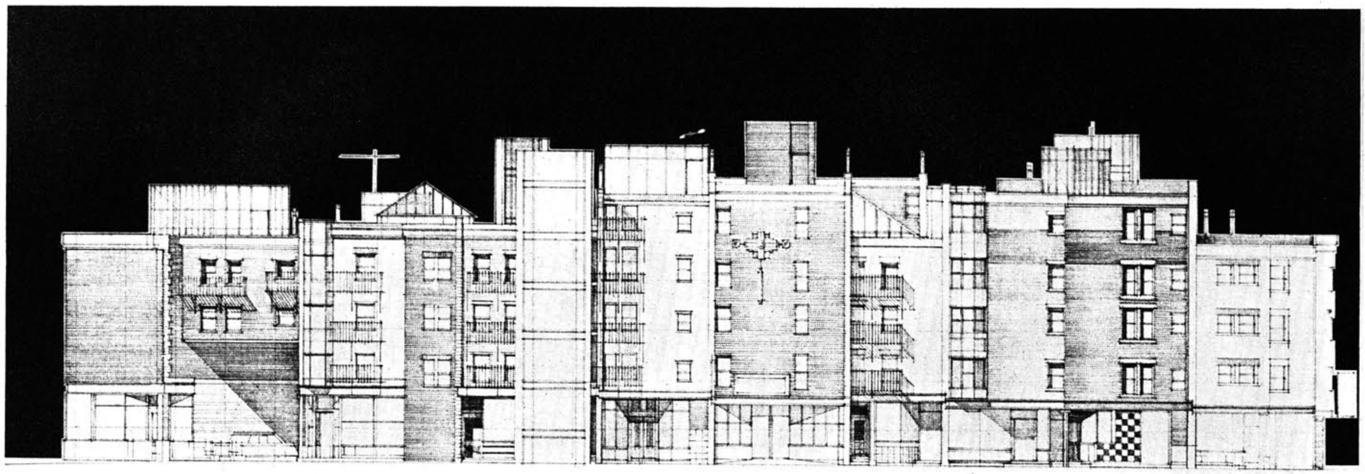
JOHN MEYER THESIS SPRING 77

3

MINE VS THEIRS WINDOW AREA 12% EFFECTIVE vs. 50%	% COST REDUCTION APARTMENT	OFFICE
1ST COST	1.9	
5 YR ENERGY	1.3	
TOTAL	3.2	
20 YR ENERGY	5.2	
20 YR TOTAL	7.1	





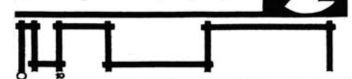


PARCEL C2B

PASSIVE ENERGY TEST SITE

16 NORTH ST.
BOSTON MA.

ELEVATION FACING NW



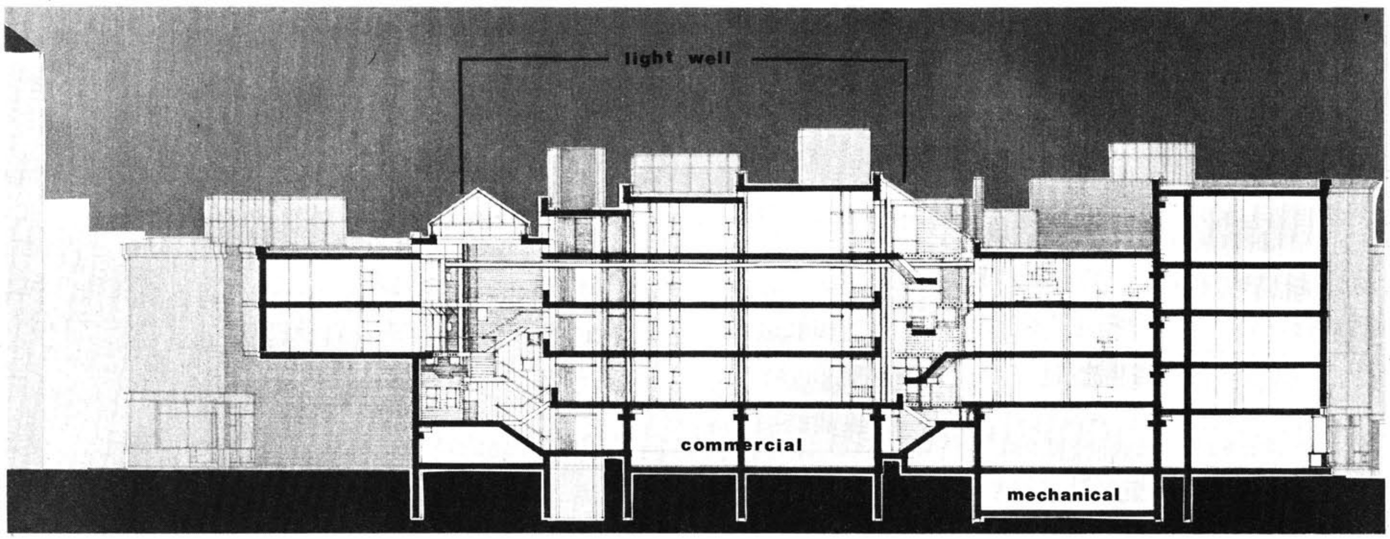
JOHN MEYER THESIS SPRING 77

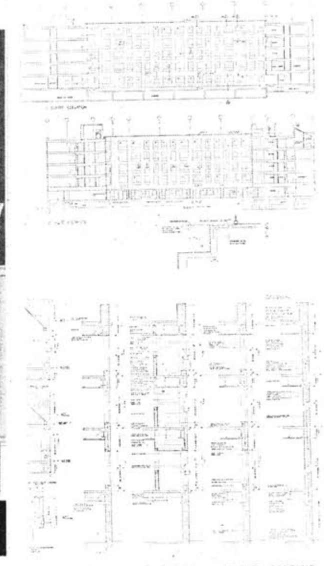
4

MINE VS THEIRS % COST REDUCTION

MASS 160#/ф vs. 40#/ф

	APARTMENT	OFFICE
1ST COST	5.5	
5YR ENERGY	3.4	
TOTAL	8.9	
20YR ENERGY	13.6	
20YR TOTAL	19.1	



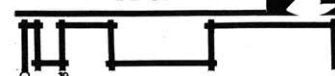


PARCEL C2B

PASSIVE ENERGY TEST SITE

16 NORTH ST.
BOSTON MA.

SECTION FACING NW



JOHN MEYER THESIS SPRING 77

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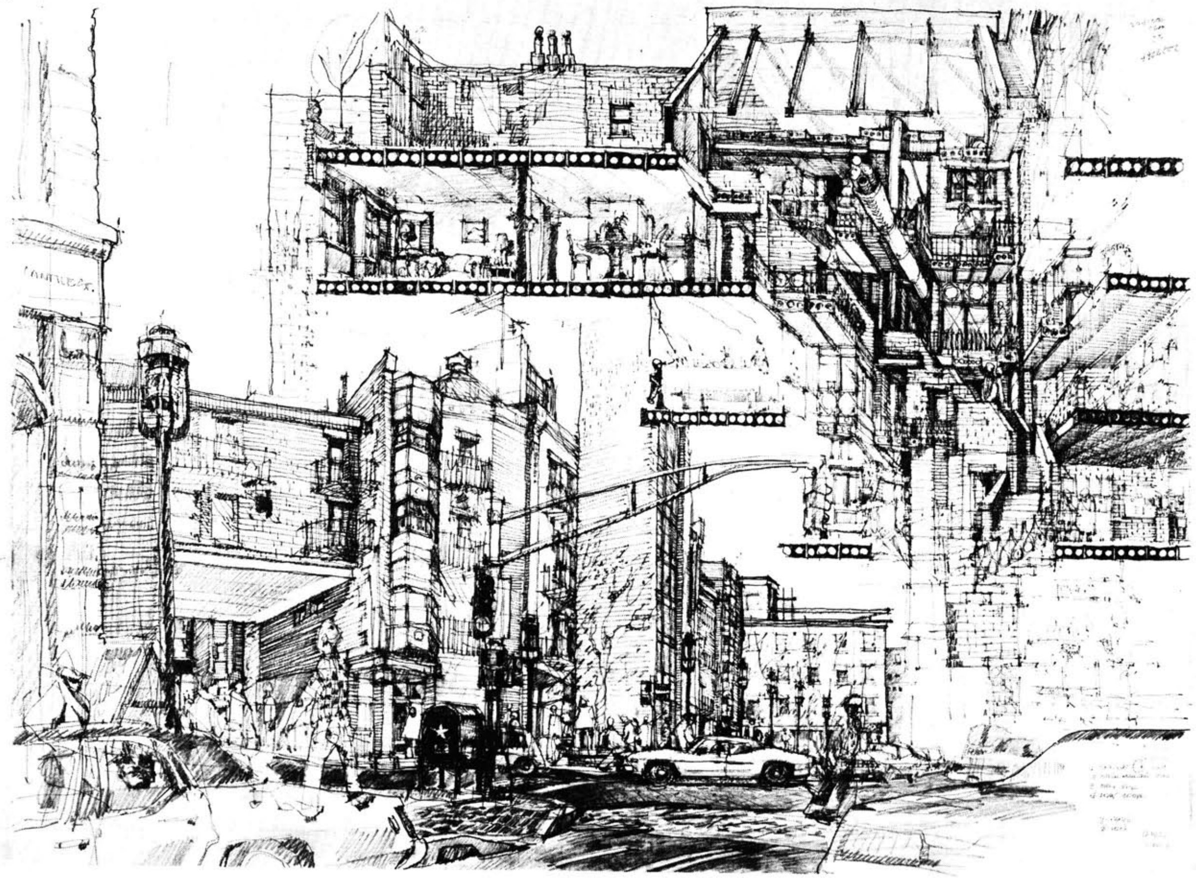

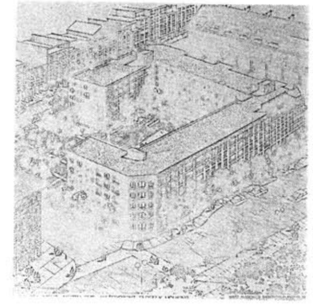

PARCEL C2B

PASSIVE ENERGY TEST SITE

16 NORTH ST.
BOSTON MA.

INSIDE
OUTSIDE

JOHN MEYER THESIS SPRING 77

6

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